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Human Physiological Responses to Shelter Environment

Report No. 2
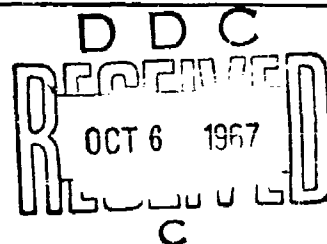
Institute for Environmental Research Kansas State University Manhattan, Kansas

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HUMAN PHYSIOLOGICAL RESPONSES

TO

SHELTER ENVIRONMENT

Report No. 2

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February, 1967

ABSTRACT

Three studies were conducted in simulated shelter environments. In the first study two experiments were conducted to determine the effects of subject-packing on changes in body temperature. Four pack conditions were studied: Condition I employed 8 subjects; Condition II employed 18 subjects; 32 subjects were used in Condition III, and Condition IV employed 48 subjects. In the first experiment, the groups were exposed to 95, 98, 100, and 105 F (DB) at 80% RH for 4 hours. The second experiment examined the physiological responses of these groups at 95 and 98 F (DB) and 60, 70, 80 and 90% RH for 8 hours. The results of the first experiment supported the hypothesis that under crowded conditions the body temperature will rise faster than under less-crowded conditions; there was also support for this hypothesis in the second experiment, however, the results were not as conclusive as in Experiment I. It was also concluded that a zone of thermal stress must be defined in terms of the number of square feet allotted to the individuals exposed since a given temperature might be stressful when the subjects were crowded and non-stressful under non-crowded conditions.

In the second study, experiments were conducted to establish stress and non-stress shelter environments for men operating a Package Ventilation Kit (PVK). If all subjects attained a 2 F rise above initial rectal temperatures within an eight hour exposure the conditions were defined as stressful; however if none of the subjects attained a 2 F rise above initial rectal temperature after an eight hour exposure, the conditions were non-stressful.

Eight college-age men were exposed to dry bulb temperatures ranging from 80 F to 100 F at 5 F increments when the relative humidity was 80%. Exposure was for a maximum of eight hours and the subjects worked (pedaled) 15 minutes and rested 15 minutes. Three work levels were studied: 0.05 hp per man, 0.10 hp per man, and 0.15 hp per man. The upper limits of the non-stressful environments were:

90 F DB, 80% RH, (86.4 F ET) at 0.05 hp/man;

85 F DB, 80% RH, (82.0 F ET) at 0.10 hp/man; and

80 F DB, 80% RH, (77.4 F ET) at 0.15 hp/man.

In the third study investigations were carried out to determine the acceptability of the water presently stored in fallout shelters and to establish the ad lib. water consumption at various thermal environments.

Six 24 hour tests at ET's of 82.0, 85.0 and 88.0 were conducted. Three groups of eight male subjects were exposed twice to one of the environmental conditions. Water which had been stored one year and fresh tap water, each at the temperature of the environment, were presented to each group.

The results indicate that the mean water intake was independent of the type of water. The mean water intake increased as ET increased and the mean water intake for all ET's was always greater than the OCD specified allotment of one quart per man/day.

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PREFACE

In July 1964, the Stanford Research Institute, Menlo Park, California activated Contract B-60729-US for research in the general area of human physiological responses to shelter environments. The objectives of the first years research for the period July 1964 through August 1965 were (1) to determine the effect of high effective temperatures on rectal temperature, pulse rate and body weight for male college-age subjects when exposed for four hours and (2) to study the effect of crowding on rectal temperature, pulse rate and body weight for male college-age subjects exposed for four hours. The results of this research were reported in Report No. 1 "Human Physiological Responses to Shelter Environments" by Rohles and Nevins dated March, 1966.

On July 14, 1965 the contract was extended to November 1966. The research objectives for the second year were: (1) to extend the crowding study to include a subject packing of six sq. ft. per person (48 subjects) and maximum exposure times of eight hours, (2) to determine the physiological capabilities of male college-age subjects to operate OCD ventilating units at high effective temperatures and (3) to determine the amount of water intake under conditions of thermal stress for college-age male subjects.

On May 27, 1966, the objectives for 65-66 were modified to (1) place the emphasis on the determination of the critical conditions for shelters and (2) to determine the effect of water quality on consumption.

This report describes the research carried out during the period September 1965 and November 1966. It contains three separate papers: (1) Physiological Effects of Subject Crowding During Exposure to Shelter

Environments, (2) Physiological Response of Male Subjects Operating OCD
Ventilating Units in Shelter Environments and (3) Water Consumption and
Preference During Exposure to Shelter Environments.

The Physiological Effects of Subject
Crowding During Exposure to
Shelter Environments

Frederick H. Rohles, Jr.
Ralph G. Nevins
Wayne E. Springer

The Physiological Effects of Subject Crowding During Exposure to
Shelter Environments[*]

In most situations, an individual loses heat by convection, radiation,
and evaporation. When these modes of heat loss are impaired by high tem-
peratures and humidities, the result is an increase in body temperature and
ultimately failure of the thermal regulatory mechanism. When these hot-
humid environments are coupled with crowded or packed conditions, it would
be predicted that the body temperature would increase at a higher rate.
Since the radiation exchange is a function of the surface temperature of the
body (skin temperature) and the surrounding surface temperatures, it is
conceivable that the radiation loss could be inhibited by the shield of
human bodies surrounding a given occupant in the packed condition. If the
wall temperatures are essentially equal to the air temperature and both are
near the body surface temperature, then the shielding or packing would not
affect the heat loss. However, if the wall temperatures are lower than
the air temperature, the benefit of increased radiation loss would be elimi-
nated by the packing. The cool wall temperatures will occur in the initial
occupancy of a shelter and in shelters surrounded by cool earth.

Since crowded conditions could be expected in shelter environments,
a hypothesis was formulated which stated that during exposure to thermal
stress, when a subject was in a packed or crowded condition, the time re-
quired for a given increment in body temperature would be less than when
in an open, unpacked condition. The purpose of this study was to test
this hypothesis.

[*]This paper constitutes an extension of the research reported under the
same title and by the same authors in Report No. 1.

METHOD

Subjects

The subjects were male high school and college students and Army personnel between the ages of 17 and 23, who had passed a physical examination designed to eliminate all individuals with a history of heat exhaustion and cardiac difficulties. All subjects wore jockey shorts, swim trunks, or cotton drawers and cotton sweat socks during the tests.

Design

Four packing conditions were studied and all testing was conducted in the KSU-ASHRAE Environmental Laboratory. In one packing condition, 8 subjects were used which resulted in 36 sq. ft. per subject. In the second packing condition, 18 subjects were exposed at a time; this condition allowed each subject 16 sq. ft. of floor space. In the third condition, 32 subjects were exposed at a time and this condition resulted in 9 sq. ft. per subject. In the fourth condition, 48 subjects were exposed at a time and this condition resulted in 6 sq. ft. of floor space per subject. Figures 1, 2, 3, and 4 show the test room under these four conditions, respectively.

Experiment I: Two experiments were conducted and each involved different thermal conditions. In Experiment I each of the pack conditions involving 8, 18, and 32 subjects was examined at 95, 98, 100, and 105 F when the RH was 80%; these are equivalent to Effective Temperatures of 90.8, 93.5, 95.2, and 100.0, respectively. However, because almost all of the subjects attained the criterion at 100 and 105 F the 48 subject-group (Group IV) was examined only at 95 and 98 F.

Experiment II: In Experiment II each of the four pack conditions was examined at 95 and 98 F at each of 4 relative humidities, 60, 70, 80, and 90 percent; the corresponding Effective Temperatures for these conditions are shown in Table 2. The maximum duration of the exposure was 8 hours, however, the subject was removed from the test condition if he became sick or met the criterion of a 2 F increment in rectal temperature.

PROCEDURE

Upon reporting to the Environmental Laboratory, oral temperatures were taken and if normal, the subjects undressed, put on jockey shorts or swim trunks and cotton socks and entered the pre-test room. Rectal temperatures and heart rates were measured by means of the MSMS (multi-subject monitoring system, see Report No. 1) and when the rectal temperatures became stabilized the subjects entered the test room. Depending upon the experiment, they remained seated in the test room for either 4 or 8 hours, unless their rectal temperatures increased 2 F above the basal rectal temperature (BRT). The time for this increment to occur was noted and the subject was removed from the test room and placed in the pre-test room until his temperature returned to its basal level. This procedure of having the subjects remain in the pre-test room until their temperatures had returned to a basal level was followed for all subjects even if their temperatures showed an increment of less than 2 F. Water was available ad lib. and during the 8 hour exposures (Experiment II) the subjects ate sandwiches and drank a cold carbonated beverage at noon; this was approximately 3 hours after entering the test room.
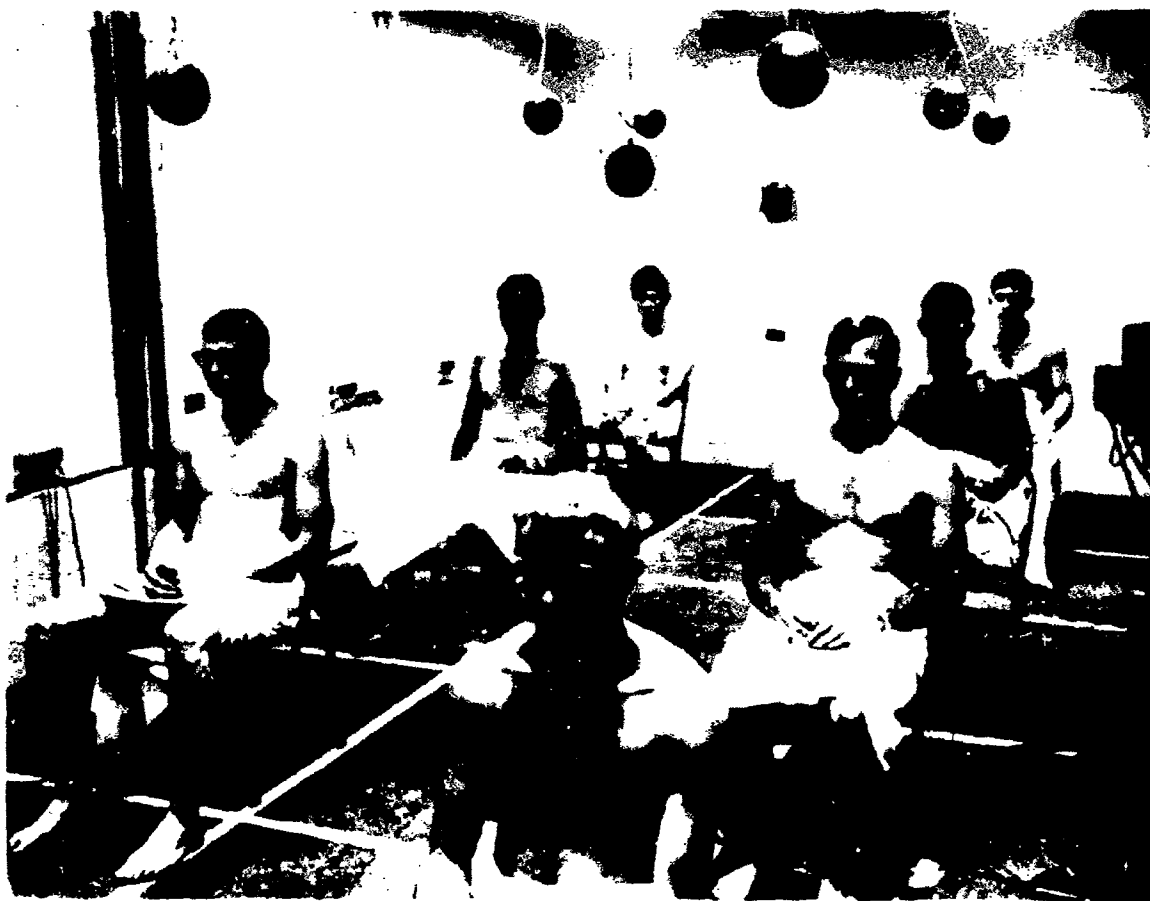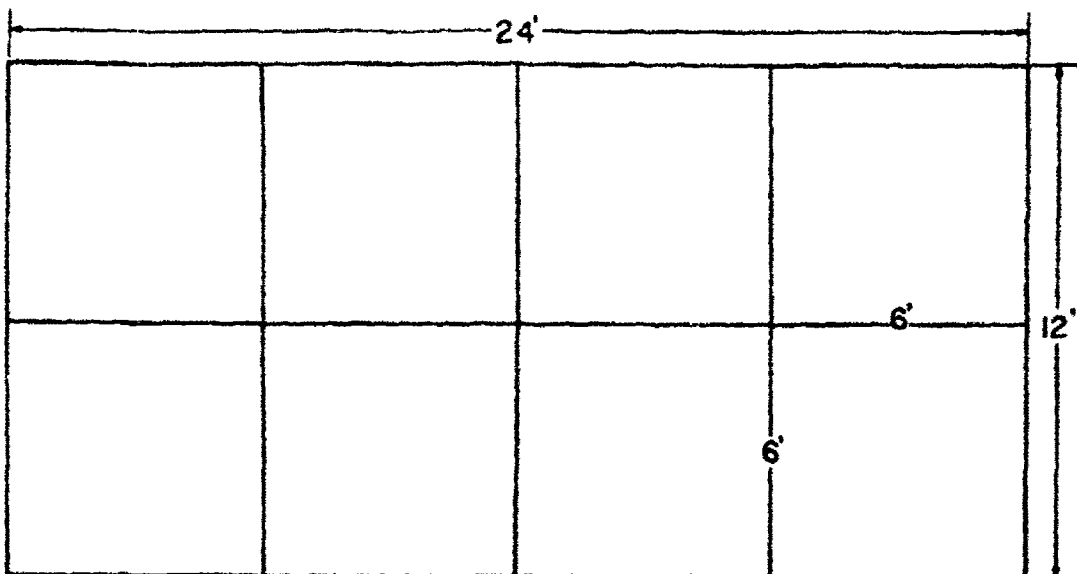
Fig. 1. Arrangement of the 8 subjects in Pack Condition I
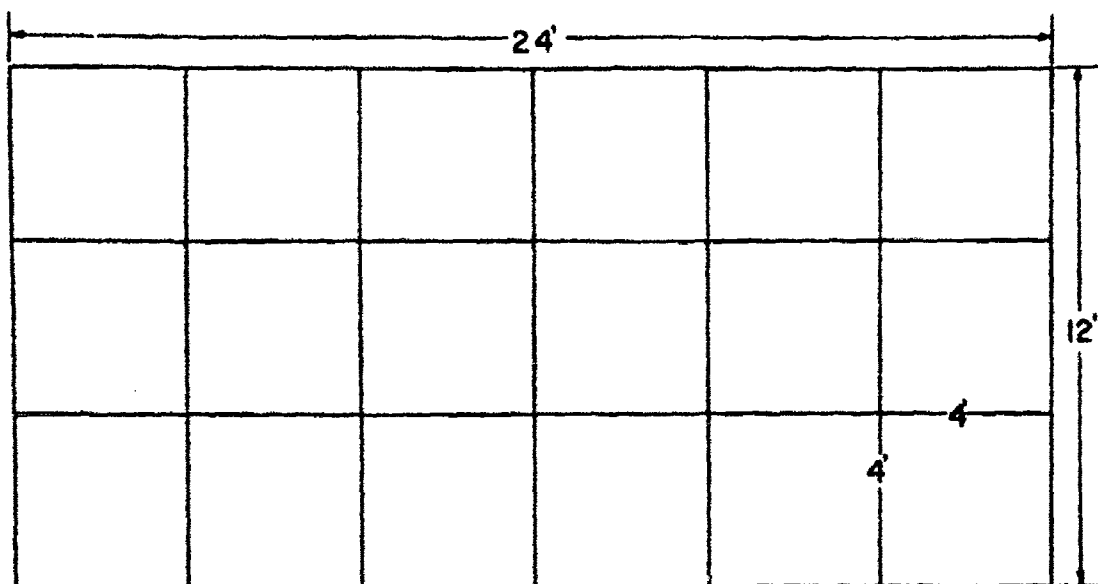
Fig. 2. Arrangement of the 18 subjects in Pack Condition II
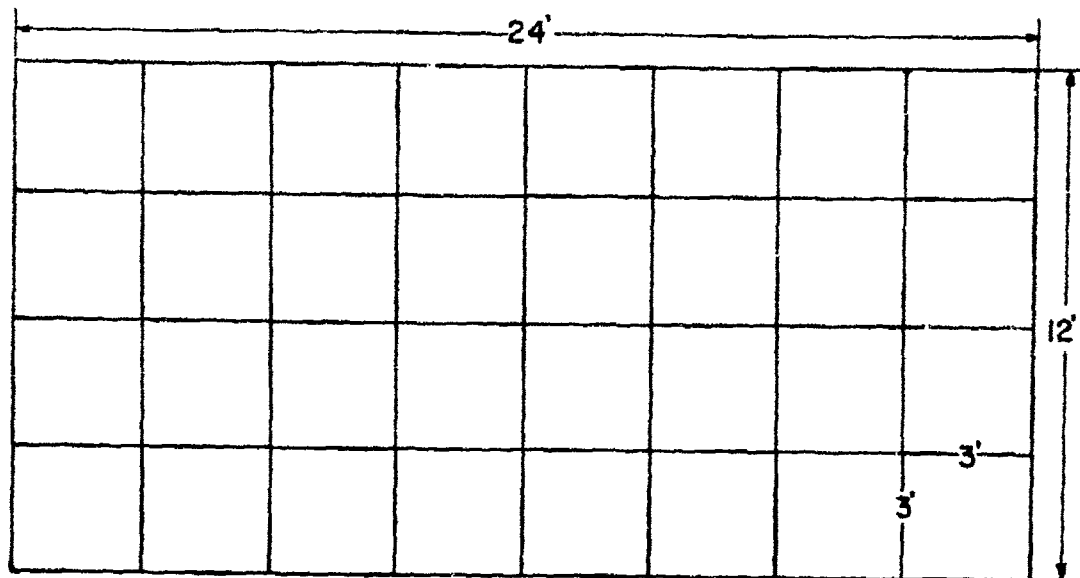
Fig. 3. Arrangement of the 32 subjects in Pack Condition III
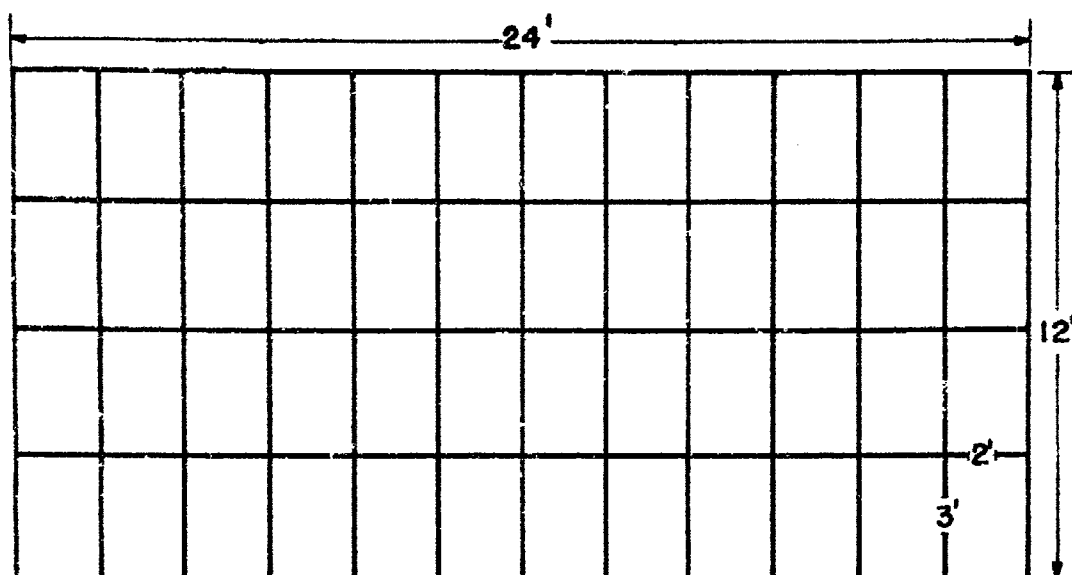
Figure 4. Arrangement of the 48 subjects in Pack Condition IV

RESULTS

The results of Experiment I which show the number of subjects in the four pack conditions who became sick or exhibited a 2 F rise in rectal temperature in less than 4 hours is presented in Table 1.

The results of Experiment II which show the number of subjects in the four pack conditions who became sick or exhibited a 2 F rise in rectal temperature in less than 8 hours is presented in Table 2. When the Effective Temperature was 93.5 (DB = 98 F, RH = 80%) and above, the subjects of the pack conditions I, II, and IV reached the criterion in 8 hours or less; however, the criterion was not attained when the exposure to the test conditions was 4 hours. The inconsistency in this trend for Pack Condition II is probably due to sample variability.

DISCUSSION

The results of Experiment I appear to support the hypothesis that increased crowding reduces the latency of the rectal temperatures response. Evidence of this effect is shown at 95 F DB in which none of the subjects reached criteria in Pack Conditions I, II, or III and 16 out of 48 or one-third of the subjects attained the criterion in Pack Condition IV. Additional evidence is shown at 98 F in which 44 and 47 percent of the subjects in Conditions II and III, respectively, and all of the subjects in Condition IV reached criterion in less than 4 hours. The response latencies at 98 F DB of 191, 177, and 133 minutes for Pack Conditions II, III, and IV, respectively, is further support of the hypothesis. In addition it must be assumed that since all of the subjects in Pack Condition IV reached

Table 1

Number of Subjects in Four Pack Conditions Who
Became Sick or Exhibited a 2 F Rise
In Rectal Temperature in Less Than 4 Hours

Dry Bulb Temp at RH 80%	ET	PACK CONDITION			
		I(N=8) +2F/Sick	II(N=18) +2F/Sick	III(N=32) +2F/Sick	IV(N=48) +2F/Sick
95	90.8	0/0	0/0	0/0	16/0
98	93.5	0/0	7/1	15/0	46/2
100	95.2	8/0	18/1	31/1	*
105	100.0	8/0	18/0	31/1	*

*No test conducted

Table 2

Number of Subjects in Four Pack Conditions Who
Became Sick or Exhibited a 2 F Rise
In Rectal Temperature in Less Than 8 Hours

Dry Bulb/ RH	ET	PACK CONDITION			
		I(N=8) +2F/Sick	II(N=18) +2F/Sick	III(N=32) +2F/Sick	IV(N=48) +2F/Sick
95/60	86.8	1/0	0/0	0/0	0/0
95/70	88.8	1/0	0/0	0/0	6/0
98/60	89.1	0/0	2/0	0/0	3/0
95/80	90.8	0/0	1/0	1/0	30/0
98/70	91.3	8/0	3/1	1/1	38/0
95/90	92.9	7/1	6/1	1/2	46/1
98/80	93.5	8/0	17/0	9/0	46/2
98/90	94.5	8/0	18/0	28/4	46/0

criterion at 98 F DB the same would be true at 100 and 105 F. Thus, on
the basis of Experiment I it is concluded that the number of square feet
available per subject is an important factor in determing the stressful
characteristics of a thermal condition. The results of the earlier report
in this series (Rohles, Nevins, and Springer, 1966) stated that 98 F, DB,
80% RH was non-stressful since none of the 8 subjects exposed to this con-
dition became sick or exhibited a 2 F rise in rectal temperature in less
than 4 hours. However the results of this study show that with the same
thermal conditions when the square foot per subject is reduced from 36
when 8 subjects are tested to 6 when 48 subjects are tested, the con-
ditions become transitional--that is to say, 16 or one-third of the sub-
jects reached criterion. Similarly, 98 F DB, 80% RH (ET = 93.5) in the
earlier report was identified as transitional when 8 subjects were tested.
This still would be the case when 18 or 32 subjects were employed, how-
ever, when 48 subjects were used, this condition became stressful since
all of thesubjects reached the criterion of sickness or a 2 F rise in
rectal temperature in less than 4 hours. Thus, it is not enough to state
that a thermal environment is stressful, transitional, or non-stressful on
the basis of reaching an arbitrary criterion because such an identifi-
cation is meaningless unless the size of the group of subjects exposed is
specified or the square footage allotted per subject is given.

While the conclusions of Experiment I are supported to some degree
in Experiment II, there are several discrepancies. Most of these appear
to come about by the tests with Pack Condition III. The same finding,
changing 95 F DB/80% RH (ET = 90.8) from non-stressful to transitional
when going from Pack Condition I to Pack Conditions II, III, or IV, was

also shown in this experiment. When considering 98 F DB/80% RH (ET = 93.5) all of the subjects reached this criterion in Pack Conditions I, II (17/18) and IV (46/48), however only 9 of the subjects in Condition III met this criterion. At 98 F DB/80% RH, the mean response latencies for the rectal temperature to increase 2 F were 169, 204, 229, and 133 min., from Pack Conditions I, II, III, and IV, respectively; at 98 F DB/90% RH, the response latencies were 91, 93, 173, and 95 min. for Pack Conditions I, II, III, and IV, respectively. Thus, while there is some agreement between the results of the 4 hour and 8 hour tests (Experiments I and II) there are too many differences to support the hypothesis that increased crowding shortens the latency of the rectal temperatures to increase 2 F. The findings do suggest that additional tests should be conducted and with a possible modification in the experimental procedure.

For example, if we are examining the effects of crowding, and we remove a subject when he has reached the criterion of a 2 F rise in rectal temperature we have, in effect, altered the crowding condition. As evidenced in experiment II when the ET was 93.5, there were 9 subjects who were removed from the test situation because of reaching criterion. This meant that there were only 23 subjects in the test room which more closely resembles Pack Condition II (N=18) than Pack Condition III (N=32). Therefore, it is believed that the procedures should be modified so that subjects who meet the criterion and are removed from the room can be replaced by new subjects and thereby keep the crowding condition constant.

SUMMARY AND CONCLUSIONS

Two experiments were conducted to determine the effects of packing

on changes in body temperature. Four pack conditions were studied: Condition I employed 8 subjects; Condition II employed 16 subjects; 32 subjects were used in Condition III, and Condition IV employed 48 subjects. In the first experiment, the groups were exposed to 95, 98, 100, and 105 F (DB) at 80% RH for 4 hours. The second experiment examined the physiological responses of these groups at 95 and 98 F (DB) and 60, 70, 80 and 90% RH for 8 hours. The results of the first experiment supported the hypothesis that under crowded conditions the body temperature will rise faster than under less-crowded conditions; while there was some support for this hypothesis in the second experiment, the results were not as conclusive as in Experiment I. It was also concluded that a zone of thermal stress must be defined in terms of the number of square feet allotted to the individuals exposed since a given temperature might be stressful when the subjects were crowded and non-stressful under non-crowded conditions.

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Physiological Response of
Male Subjects Operating OCD
Ventilating Units in Shelter Environments

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Physiological Response of Male Subjects
Operating OCD Ventilating Units in Shelter Environments

INTRODUCTION

Ventilation of shelters is most likely to be necessary to cool the occupants rather than provide adequate oxygen and carbon dioxide removal. The use of the bicycle ventilation unit requires added work output by some of the occupants of a shelter when there is no electrical power available. Therefore, it is necessary to investigate the thermal environment limits for healthy young adult subjects operating the ventilating units at various feasible work rates and cycle times.

METHOD

The tests were performed in the KSU-ASHRAE Environmental Test Room described by Nevins et al. (1).* This room is 12' x 24' in plan and has been used for other tests conducted under this contract.

Package Ventilator Kit

The ventilators, one of which is shown in Figure 1, were two-seat modular units (Packaged Ventilation Kits, PVK), described by Work Unit 1423 A under Office of Civil Defense contract No. OCD-PS-64-22. They were obtained through SRI, from the manufacturer, General American Transportation Corporation. Two of these units were employed throughout the experiment, which permitted 4 subjects to pedal and 4 subjects to rest at any time. The fan was modified with a short duct, flow straightener, piezometer ring and damper. The damper could then be adjusted to provide the required power load on the operators. A manometer reading of fan static pressure was used to indicate the power level. Figure 1 shows a schematic drawing of the unit as modified. The assembly was calibrated for power input by

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*Numbers in parentheses refer to references at the end of this paper.
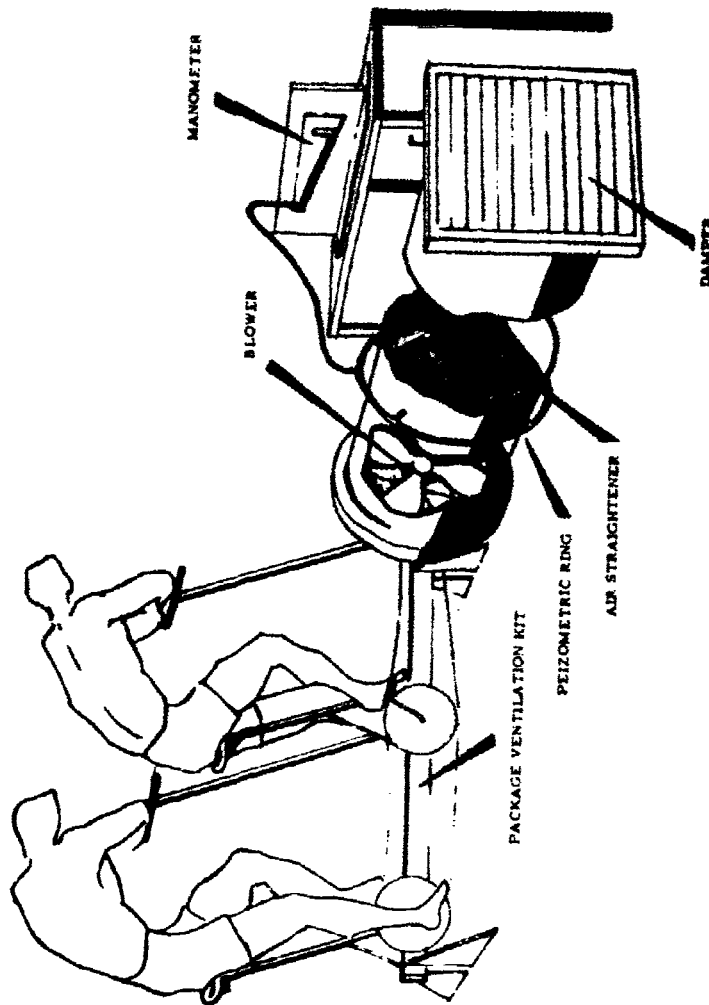
FIGURE 1 Schematic of the Two-Seat Modular
Packaged Ventilation Kit Used in this Study

operation of the unit at one of the pedal cranks with a cradled dynamo-
meter. Appendix A gives this calibration procedure. In this way, the power load
on the two operators could be adjusted. A marker was placed on the indicating
manometer at the desired value. The operators pedalled so as to main-
tain the outlet pressure at this value (at the marker) during the tests.
A timer was used to produce an auditory and visual signal at fixed inter-
vals and served to cue the subjects' response for each desired pedal
crank revolution which, in turn, insured maintenance of the proper power
level.

Plywood baffles were used to shield the operators and the resting
subjects from the cooling effects of the moving air. The two units were
placed so as to direct the main air stream away from the subjects. Air
velocities around each subject were measured for all test conditions by
a hot wire anomometer. The results and procedures of this air velocity
survey are listed in Appendix B.

Duration of Tests

Eight hours was selected as the test duration. This is a practical
work cycle and certainly as long as would be used in a shelter, where
adequate numbers of persons would be available. A literature search
on work rates suggested that a 15 minute work cycle was reasonable, and
to equalize the load on each subject, equal work and rest cycles were
selected. Therefore, the 8 subjects were organized in teams of 2 each.
Two teams were assigned to each PVK, so that each was in continuous operation.

Work Rate Selection

Previous research shows that healthy males should be able to work
at 0.1 horsepower. For these tests, it was felt that in an 8 hour period,
this rate should be less. Therefore, the highest work rate (high activity
level) used was nominally 0.15 hp per person while pedaling, giving a 0.075

hp mean rate for the entire 8-hour period. This level was lowered to 0.1 hp for the medium activity level and 0.05 hp for the low level while pedalling. Appendix A shows that the actual work rates of the three levels were very close to nominal, being:

0.1515 hp per subject - High Activity Level

0.0975 hp per subject - Medium Activity Level

0.051 hp per subject - Low Activity Level

The nominal values will be used in the discussion and presentation of the results.

Subject Selection

Two groups of 8 college-age males between the ages of 17 and 25 served as subjects. All successfully passed physical examinations by the KSU Student Health Service designed to eliminate individuals with histories of heart problems, heat exhaustion, etc. In addition, none had a history of knee injurys, which would make it difficult to perform the work task assigned.

Physical and Physiological Measurements

Rectal temperatures were monitored every 5 minutes by the Multi-Subject Monitoring System described in Report #1 under this contract. Figure 2 shows a typical rectal probe and jack used. Figure 3 shows the indicating and recording equipment in the remote monitoring room. Blood pressure and pulse rates were taken before and after the 15 minute work cycle on a prescribed schedule. Figure 4 shows this procedure in the test room.

Each subject was weighed before and after the test and his height measured. Figure 5 shows this procedure in the pretest room. In addition, his water intake, urine output and food intake were measured.

FIGURE 2   Typical Rectal Probe and Test Room Jack
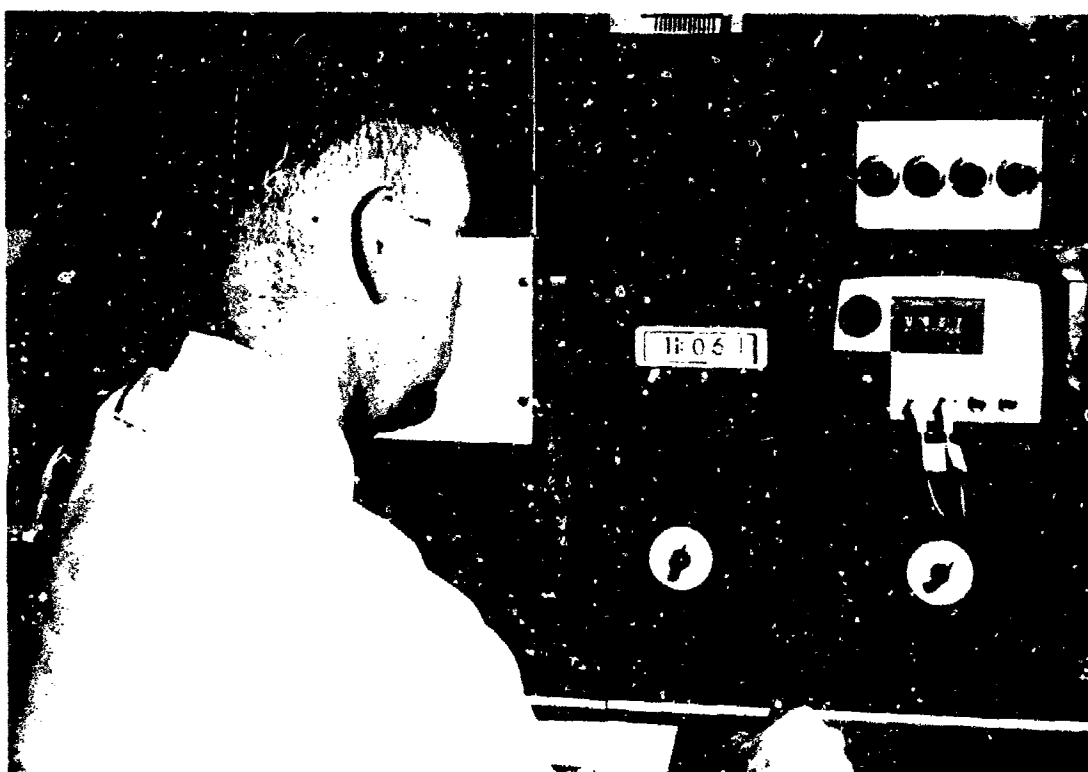
FIGURE 3 Indicating and Recording Thermometer
Located in Remote Monitoring Room

FIGURE 4 Monitoring Blood Pressure in the Test Chamber
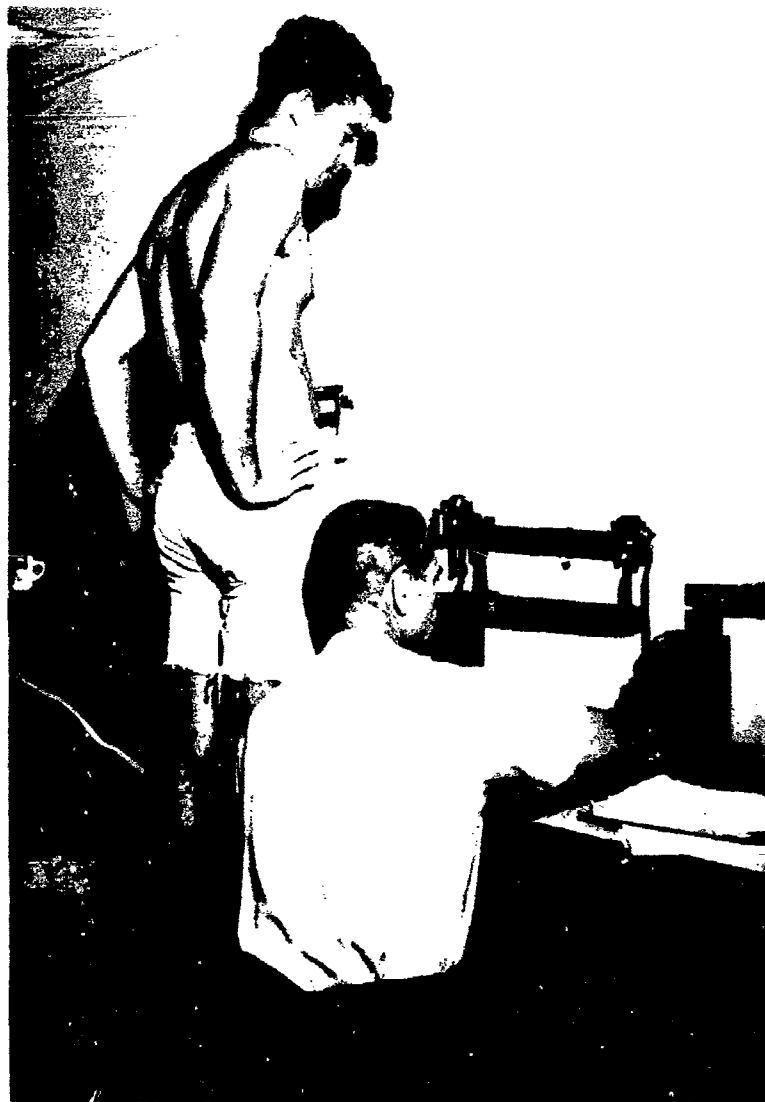
FIGURE 5   Weigh-in Procedure in Pretest Room

The water content of the food was not measured, but no beverages, juicy fruits, salads, etc. were available. Appendix C lists the sample menus used.

Earlier studies conducted for this contract employed elevation of rectal temperature as a stress index. However, because work rates greater than sedentary were involved, blood pressures and pulse rates were added to the list of physiological stress indices. These measures and maximum allowable limits are listed below together with the rectal temperature criterion used previously. If a subject reached or exceeded one or more of the criteria listed he was removed from the test.

1. Rectal Temperature - 2F rise above a stable pretest level for each subject, called Basal Rectal Temperature BRT.

2. Blood Pressure - Systolic - 180 mm Hg

3. Pulse Rate - 180 beats per minute

4. Exhausted - Nurse's judgement

5. Sick - Nurse's judgement

Environmental Conditions

Previous work under this contract and literature surveys were used to predict the conditions of stress, non-stress and transition. These three conditions which were to be determined by the tests are defined as:

non-stress: the maximum thermal environmental conditions in which all the subjects can remain for the duration of the test at the activity level of the test without reaching one of the limiting criteria;

transition: the range of thermal environmental conditions in which some subjects fail to remain for the duration of the test at the activity level of the test, having reached one or more of the

limiting criteria (this is the zone where subject variability con-
trols the results);

stress: minimum thermal environmental conditions where no subject
can remain for the duration of the test at the activity level of
the test without reaching one or more of the limiting criteria.

Calculations were made (see Appendix D) to estimate the environmental
conditions for the three zones listed above for each of the three work
rates. A single relative humidity, 80% was used as being the most likely

TABLE 1

Experimental Conditions and Predicted
Zones of Stress, Transition and Non-Stress

DB (F)	RH (%)	ET (F)	Low Activity Level	Medium Activity Level	High Activity Level
100	80	95.2	S		
95	80	90.8	NS	S	S
90	80	86.4		NS	T
85	80	82.0			NS
80	80	77.5			

S - Stress Zone (all subjects reach a stress criteria in 8 hours or less)

T - Transition Zone (some of the subjects reach a stress criteria in
8 hours or less)

NS - Non-Stress Zone (none of the subjects reach a stress criteria in
8 hours or less)

practical value. This made possible the determination of a single environmental
conditions for each zone. This decision was further justified by previous
work under this contract which shows excellent agreement of the zones with
ET, which can be easily compared at RHs other than 80%. Nine test conditions
were required. For further validity, it was decided to replicate the stress

and non-stress conditions with both groups of subjects. This experimental
design provided for a minimum of 15 tests with 8 subjects each. In addition,
the tests were randomized by presenting the experimental conditions and
work rates as shown by the schedule in Appendix E. In general, no subject
was used more than twice each week, and the high work rates were presented
early in the schedule. Appendix D shows detailed calculations to establish
the predicted thermal conditions for the stress, transition and non-stress
zones. These estimates are shown in Table I.

PROCEDURE

On the day of a test, eight subjects entered the pretest room at 1300
hours dressed in undershorts, bermuda shorts, cut-offs, or swim trunks,
and sweat socks to have their height and weight recorded. They were
given a general examination by the nurse and no subject was allowed to
participate who was judged by the nurse to be ill. The pretest room
was maintained at a comfortable level, 75 - 78 F dry bulb temperature, and
the relative humidity was approximately 40%. After the subjects had
inserted their rectal probes to an approximate depth of six inches, they
were seated in the pretest room for approximately one hour. During this
period rectal temperatures were recorded at five minute intervals by
means of the Multi-Subject Monitoring System, (see Figures 2 and 3).
When stabilized, this pretest temperature then served as the subject's
initial or basal rectal temperature (BRT). All tests began at approximately
1400 hours and initial pulse rates and blood pressures were recorded
for each subject immediately before he entered the test room.

When subjects entered the test room they attached their rectal probes
to the numbered wall-jacks. They were then paired into 4 teams of
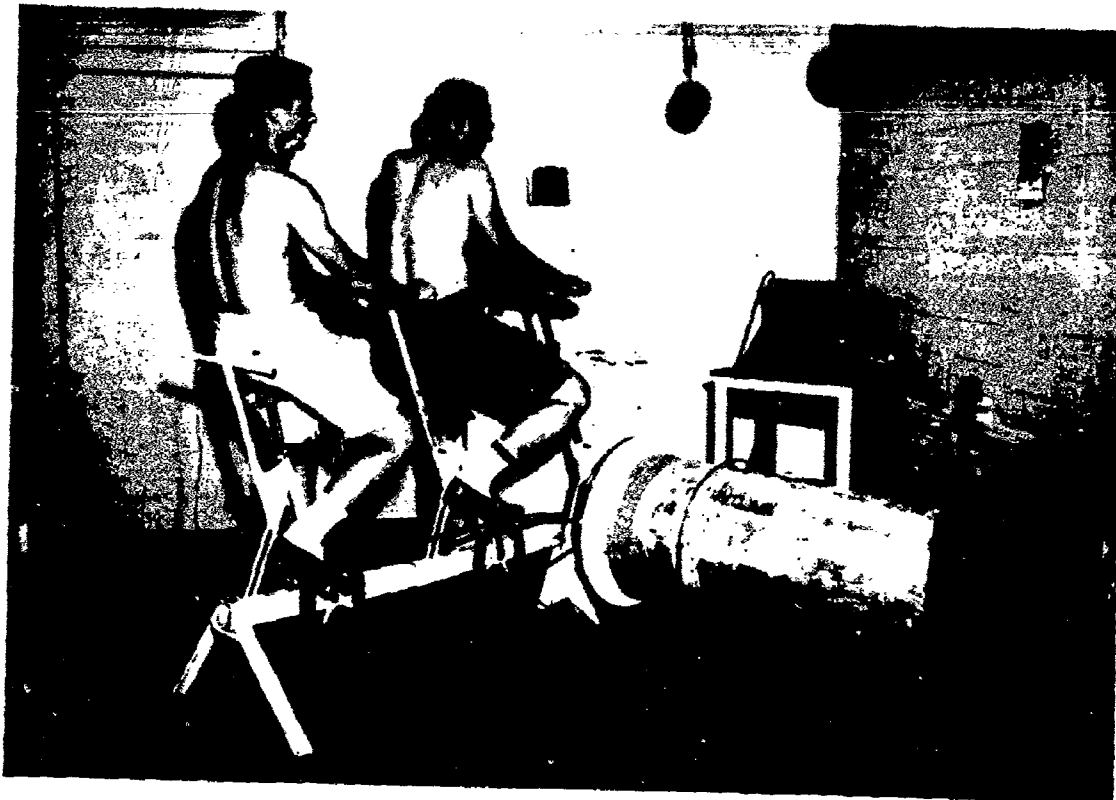
FIGURE 6 Typical Team Operating the PVK in the Test Room

2 men each and two teams were assigned to each PVK. Pulse rates and blood pressures were taken before and after riding according to the prescribed schedule. One te. . began pedalling five minutes before the other to permit time for the nurse and her assistant to record the data for both teams. Figure 6 shows a typical team in operation in the test room. When one team finished the 15 minute work cycle, they were allowed to rest in chairs provided behind air baffles to minimize air velocity over the subjects. Then the other team assigned to that PVK began their 15 minute work cycle. Towels were provided to remove perspiration. All food consumed was weighed and subjects ate their meals during their rest period at about 1700.

To maintain the proper work rate the riders matched their pedalling with a timed light which flashed, and a clicker. In addition, the static pressure on an oil manometer attached to a piezometric ring on the fan duct provided a second index that insured maintenance of the proper work level. All urine was collected and weighed for each subject. If a subject reached one of the stress criteria he was removed from the test room and immediately weighed. He was provided with a clean, dry towel and sheet. His pulse rate and blood pressure were then recorded and subsequently monitored along with rectal temperature every 20 minutes for an hour after leaving the test, or longer if, in opinion of the nurse he needed further observation. His partner remained in the test serving as a substitute for any other subjects that subsequently reached one of the stress criteria so that continuous data could be preserved on as many subjects as possible. Any subject who became a substitute was monitored only for his own safety; his subsequent data were not recorded. The reason and time for removing a subject was always listed.

RESULTS

Table 2 shows the stress, transition, and non-stress zones as defined above for the activity levels considered in this study. Also presented are the zones established previously under this contract for sedentary activity level (0.00 hp work rate) with eight subjects exposed for an eight hour period. The mean radiant temperature was maintained equal to dry bulb temperature in all cases and the air velocities in the vicinity of the subjects were measured in the 50 to 80 feet per minute range.

TABLE 2

Lower Thermal Limits of Stress Zones, Upper Limits of
Non-Stress Zones and Areas of Transition Resulting from These Experiments

DB (F)	RH (%)	ET (F)	Work Rate (hp/man)			
			0.00	0.05	0.10	0.15
105	80	100.0	S			
100	80	95.2	T	S		
95	80	90.8	NS	T	S	S
90	80	86.4		NS	T	T
85	80	82.0			NS	T
80	80	77.4				NS

S = Stress Zone (all subjects reach a stress criteria in 8 hours
or less)

T = Transition Zone (some of the subjects reach a stress criteria
in 8 hours or less)

NS = Non-Stress Zone (none of the subjects reach a stress criteria
in 8 hours or less)

Table 3 shows the summary data for all subjects for which continuous data were available in each zone. Included are the number of subjects removed from a test having reached a 2F rise in rectal temperature and

the number of subjects removed for reaching other stress criteria.

The total number of subjects may differ from multiples of eight since only data from subjects who were able to remain on the assigned work-rest cycle continuously until removal from the test room were considered. As stated previously, a subject's work schedule was interrupted whenever his partner was removed and a substitute was not available to preserve the data for the remaining subject.

TABLE 3

Number of Subjects with Continuous Measures and Number of
Subjects Removed from Test after Attaining a Stress Criteria

DB (F)	RH (%)	ET (F)	Activity Level (hp/man)					
			0.05 N	T/O*	0.10 N	T/0	0.15 N	T/0
100	80	95.2	15	13/2				
95	80	90.8	6	4/0	12	9/3	18	17/1
90	80	86.4	16	0/0	7	1/1	7	2/0
85	80	82.0			16	0/0	7	1/1
80	80	77.4					16	0/0

*N = Total number tested

T = Number with 2 F rise above BRT

O = Number reaching other criterion

Table 4 presents the means and standard deviations for the continuous measures obtained for subjects under each test condition. Included is the mean time to reach a 2 F rise in rectal temperature for those subjects who attained that criteria. Rates of weight loss and sweat loss are presented in both pounds per square foot of body surface area per hour and grams per square meter of body surface area per hour. Percent sweat

TABLE 4

Means and Standard Deviations* of Physical and Physiological Measurements

High Activity Level (0.15 hp/man)

	No.**	Age (Yrs)	Height (In)	Weight (lb)	Surface Area (ft2)	Water Consumption (lb/hr)	Sweat Rate (lb/ft2hr)	Sweat Rate (gm/m2hr)	Weight Loss (lb/ft2hr)	Weight Loss (gm/m2hr)	Sweat Rate (%/hr)	Weight Loss (%/hr)	Time to 2F Rise (hr)
STRESS ET = 90.8F	18	19.8 (3.0)	72.0 (2.9)	166.84 (18.48)	21.26 (1.47)	1.19 (0.31)	0.103 (0.037)	503 (181)	0.044 (0.058)	215 (283)	1.32 (0.43)	0.58 (0.39)	1.51 (0.92)
TRANSITION ET = 86.4 F	7	18.4 (1.8)	72.6 (3.3)	168.18 (16.74)	21.46 (1.47)	0.63 (0.26)	0.047 (0.008)	229 (40)	0.016 (0.010)	78 (49)	0.60 (0.17)	0.21 (0.14)	2.05 (1.45)
TRANSITION ET = 82.0 F	7	20.3 (2.0)	70.4 (1.1)	165.57 (16.57)	20.86 (0.79)	0.48 (0.36)	0.046 (0.009)	225 (44)	0.016 (0.026)	78 (127)	0.58 (0.17)	0.21 (0.36)	0.75 —
NON-STRESS ET = 77.4 F	16	19.5 (3.0)	71.2 (1.8)	169.75 (22.62)	21.24 (1.12)	0.49 (.14)	0.038 (0.013)	186 (63)	0.011 (0.015)	48 (78)	0.47 (0.20)	0.13 (0.20)	— —

Medium Activity Level (0.10 hp/man)

	No.**	Age (Yrs)	Height (In)	Weight (lb)	Surface Area (ft2)	Water Consumption (lb/hr)	Sweat Rate (lb/ft2hr)	Sweat Rate (gm/m2hr)	Weight Loss (lb/ft2hr)	Weight Loss (gm/m2hr)	Sweat Rate (%/hr)	Weight Loss (%/hr)	Time to 2F Rise (hr)
STRESS ET = 90.8 F	12	19.8 (3.2)	71.6 (3.2)	171.34 (19.33)	21.41 (1.45)	0.76 (0.59)	0.080 (0.028)	391 (136)	0.043 (0.028)	215 (136)	1.01 (0.35)	0.55 (0.37)	2.47 (1.07)
TRANSITION ET = 86.4 F	7	19.3 (2.3)	70.6 (3.6)	167.06 (24.90)	20.99 (1.88)	0.85 (0.26)	0.051 (0.016)	249 (78)	0.007 (0.006)	34 (29)	0.65 (0.24)	0.08 (0.26)	1.58
NON-STRESS ET = 82.0 F	16	18.9 (2.7)	70.9 (2.5)	167.02 (20.04)	21.04 (1.44)	0.47 (0.20)	0.033 (0.007)	161 (34)	0.007 (0.008)	24 (39)	0.42 (0.05)	0.08 (0.10)	— —

Low Activity Level (0.05 hp/man)

	No.**	Age (Yrs)	Height (In)	Weight (lb)	Surface Area (ft2)	Water Consumption (lb/hr)	Sweat Rate (lb/ft2hr)	Sweat Rate (gm/m2hr)	Weight Loss (lb/ft2hr)	Weight Loss (gm/m2hr)	Sweat Rate (%/hr)	Weight Loss (%/hr)	Time to 2F Rise (hr)
STRESS ET = 95.2 F	15	19.3 (2.9)	71.6 (2.9)	168.92 (20.09)	21.27 (1.47)	1.44 (0.75)	0.112 (0.028)	547 (136)	0.043 (0.048)	210 (234)	1.41 (0.35)	0.55 (0.61)	1.05 (0.20)
TRANSITION ET = 90.8 F	6	21.5 (2.7)	71.0 (4.3)	186.79 (16.10)	22.10 (1.23)	1.10 (0.31)	0.067 (0.012)	327 (59)	0.012 (0.014)	59 (68)	0.80 (0.15)	0.15 (0.18)	5.93 (1.00)
NON-STRESS ET = 86.4 F	16	20.4 (3.0)	71.2 (2.6)	168.20 (19.68)	21.16 (1.30)	0.51 (0.20)	0.032 (0.008)	156 (39)	0.006 (0.008)	29 (39)	0.41 (0.08)	0.08 (0.11)	— —

*Standard Deviation in parentheses. **Number of subjects with continuous data.

and percent weight loss per hour are computed by dividing total loss by the product of individual exposure time and initial weight. Weight loss is computed as initial weight minus final weight.

Figure 7 compares mean exposure time and effective temperature for all subjects with continuous data.

Figure 8 demonstrates the trend of sweat rate as related to effective temperature and Figure 9 shows the relationship between weight loss rate and effective temperature. The zones of stress, transition and non-stress are indicated on each figure. These figures represent results only for those subjects with continuous data. The relationships of percent of sweat loss and weight loss per hour vs effective temperature are identical with those of sweat rate and weight loss rate per unit surface area vs effective temperature; therefore, only the latter are presented here.

Figure 10 shows the water consumption vs effective temperature for all subjects with continuous data.

Figure 11 shows the observed sweat rates vs predicted metabolic rates (computed in Appendix D).

Figure 12 is the temperature history of three representative subjects during a test exposure.

Figures 13, 14, and 15 show plots of the mean pulse rates and Figures 16, 17, and 18 show plots of the mean systolic and diastolic blood pressure for each test condition at entrance to test, at removal from test, and after one hour of post-test recovery. Table 5 presents means and standard deviations of pulse rate and blood pressure data.

DISCUSSION

In evaluating the performance of an individual working under shelter conditions operating a PVK, an important consideration is the length of time that a subject can maintain a constant work load without experiencing significant thermal stress. An indication of the magnitude of exposure time for given shelter environment that an individual would be expected
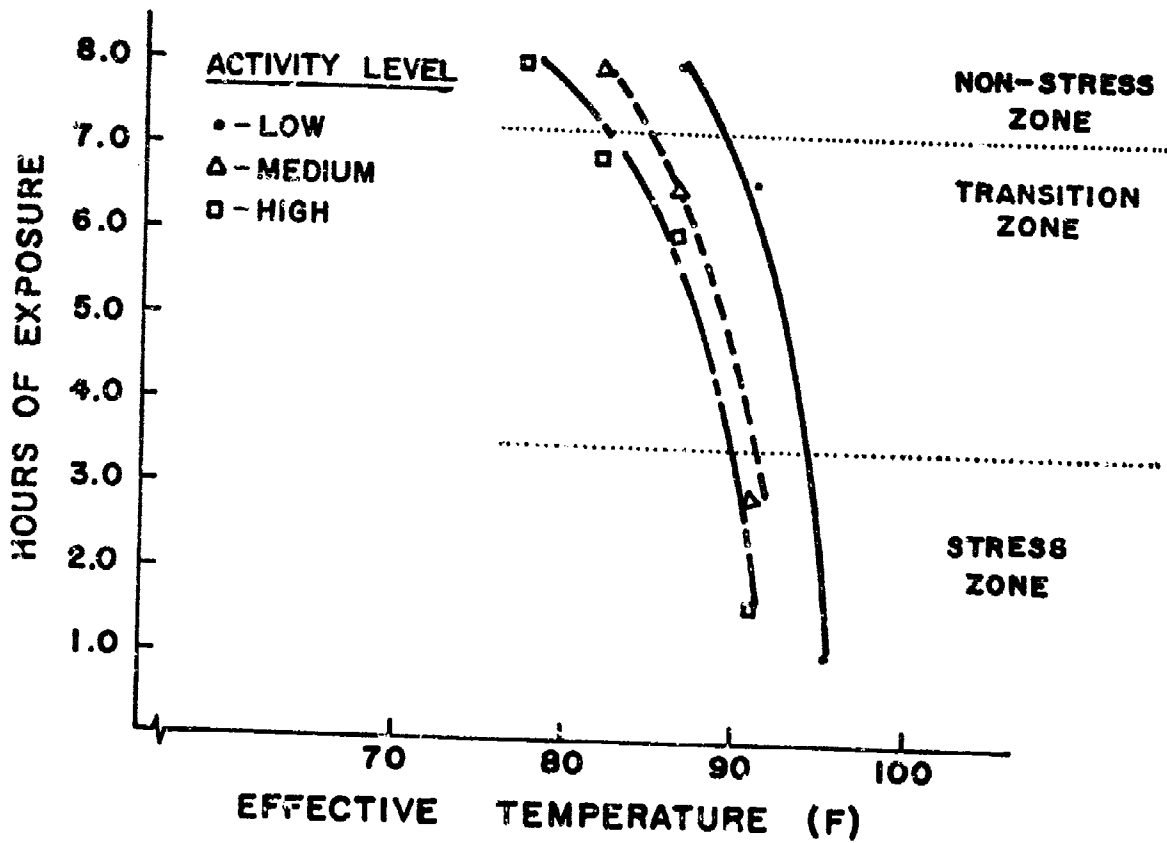
FIGURE 7 Exposure Time vs. Effective Temperature for a Maximum
Exposure of 8 Hours at a High, Medium, and Low Activity Level.
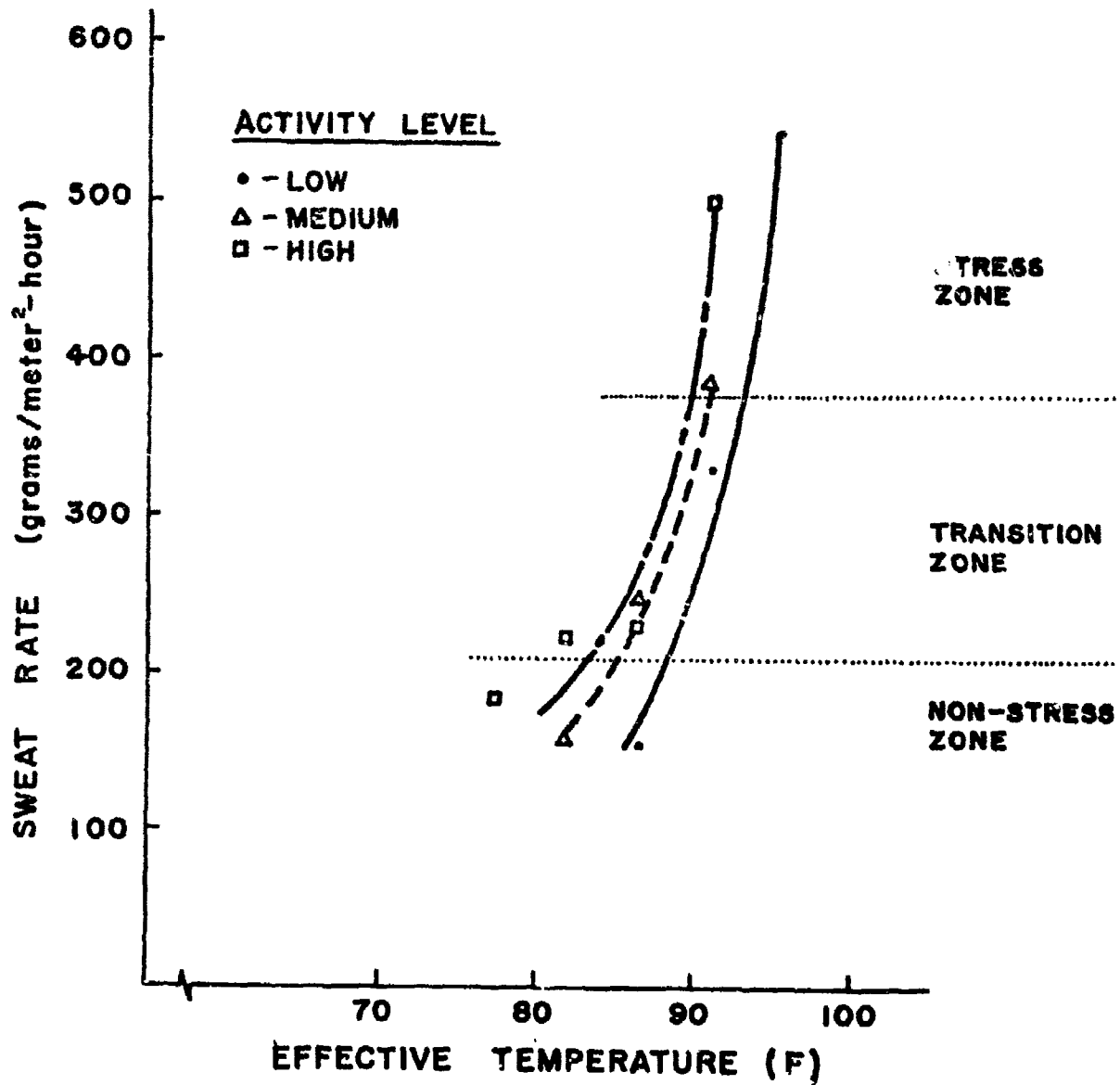
FIGURE 8 Sweat Rate vs. Effective Temperature
for a High, Medium, and Low Activity Level.
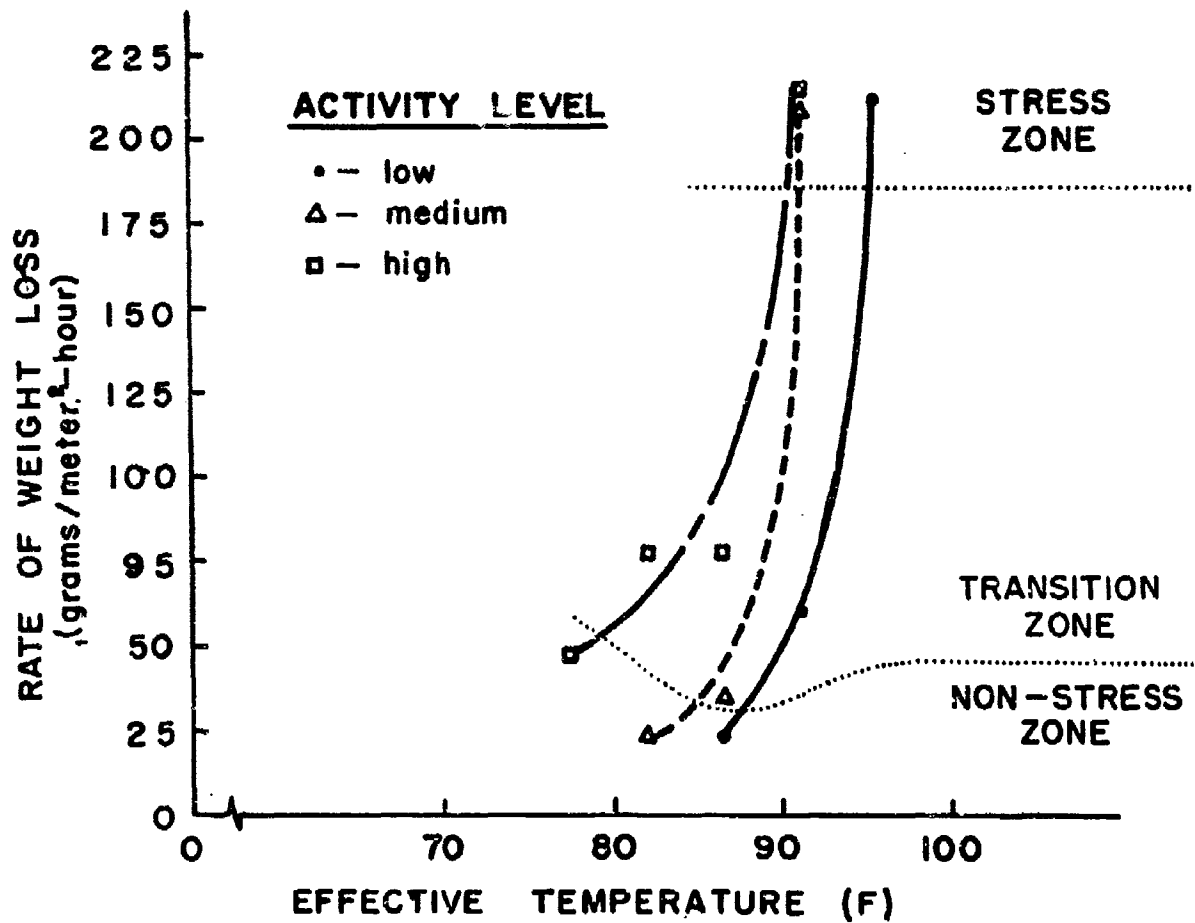
FIGURE 9 Rate of Weight Loss vs. Effective Temperature
for a High, Medium, and Low Activity Level.
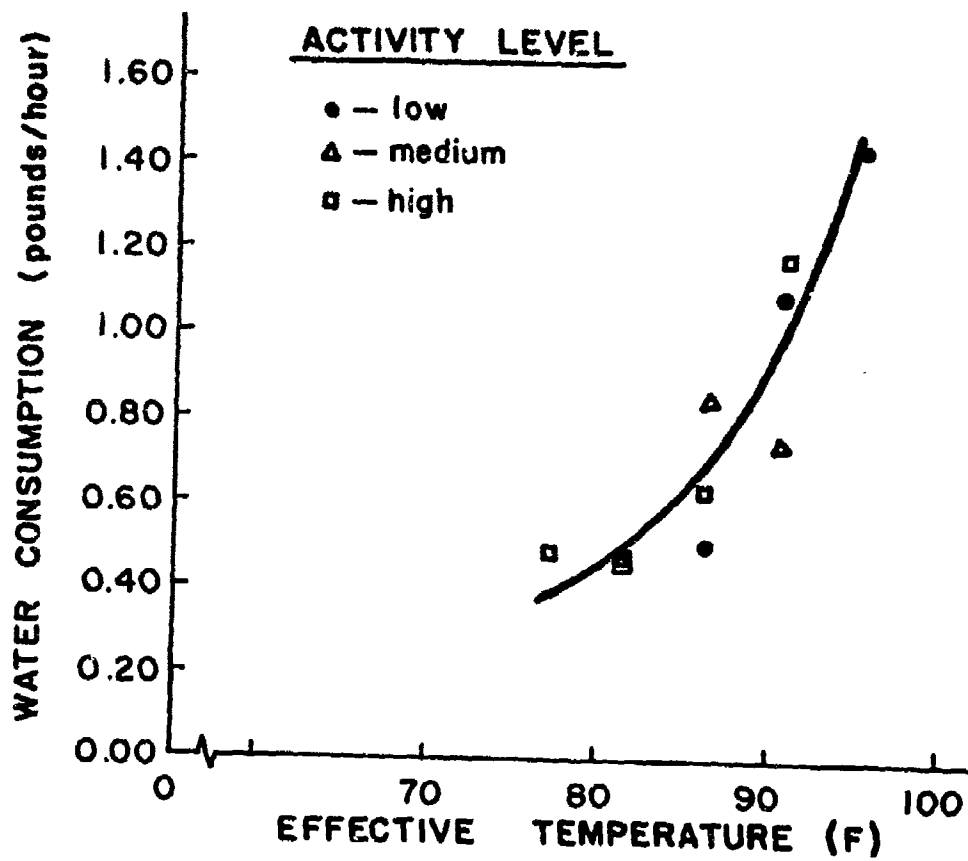
FIGURE 10 Water Consumption vs. Effective Temperature for a High, Medium, and Low Activity Level.
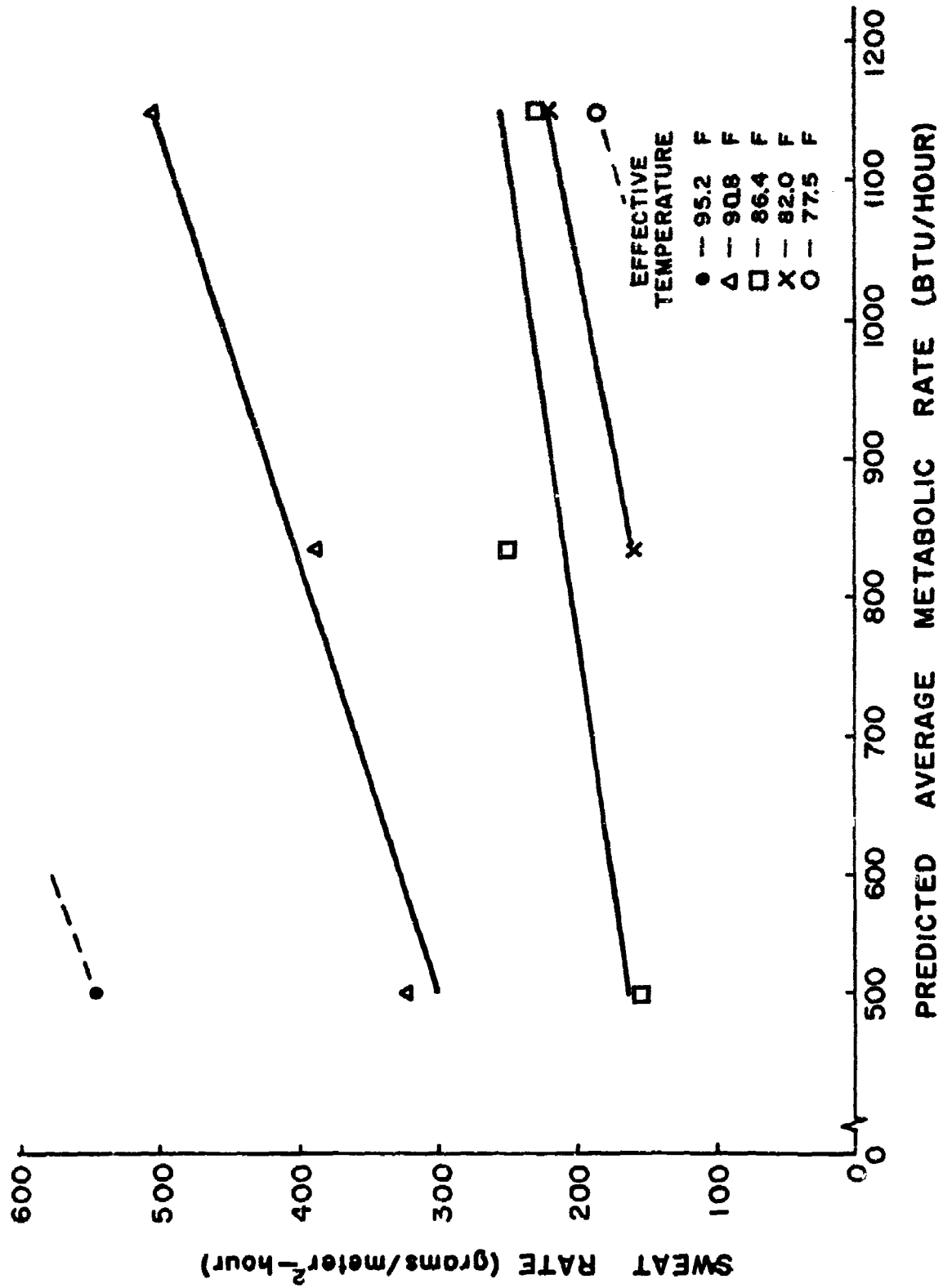
FIGURE 11 Sweat Rate vs. Predicted Average Metabolic Rate.
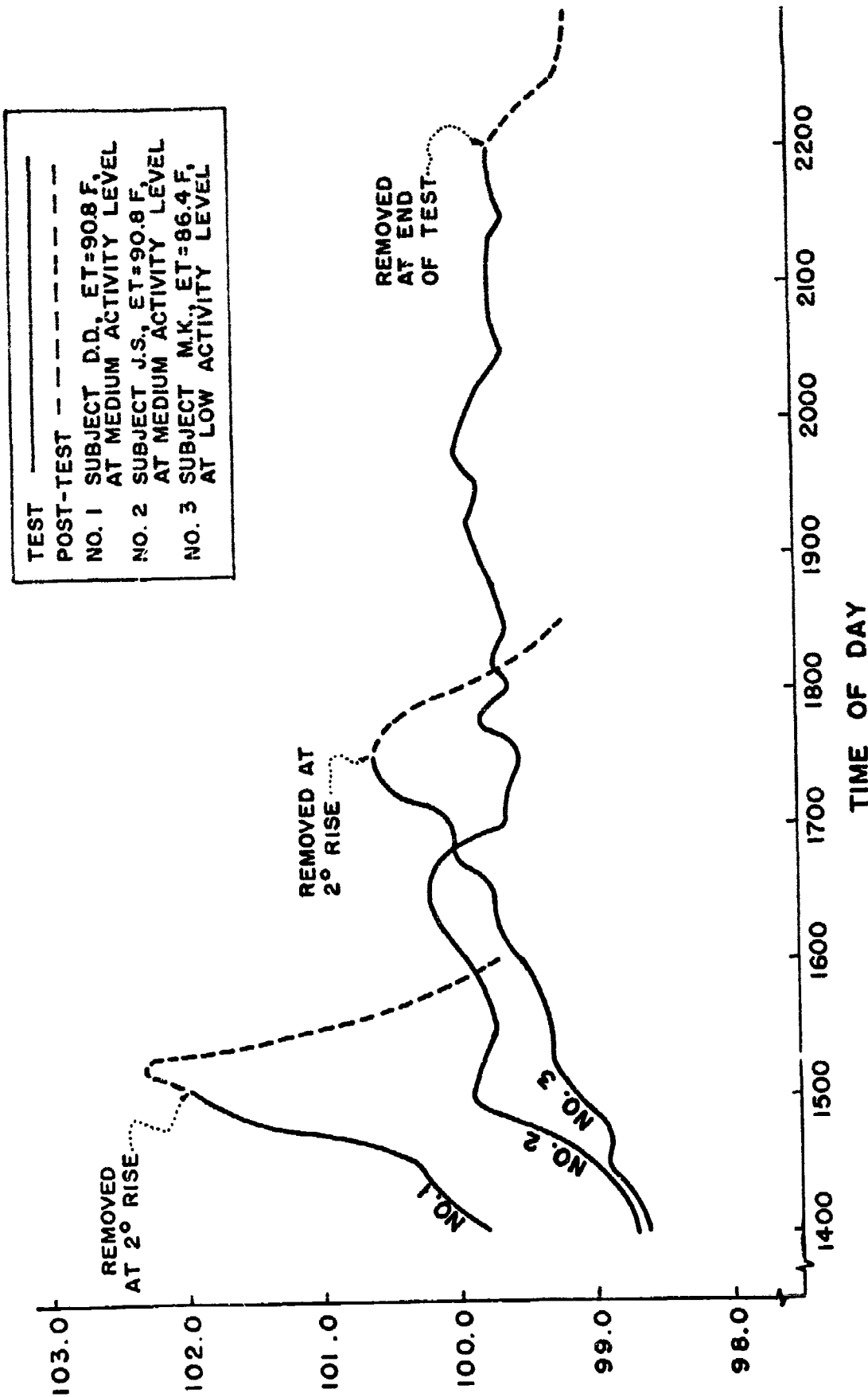
FIGURE 12 Temperature History of Three Representative
Subjects During a Test Exposure
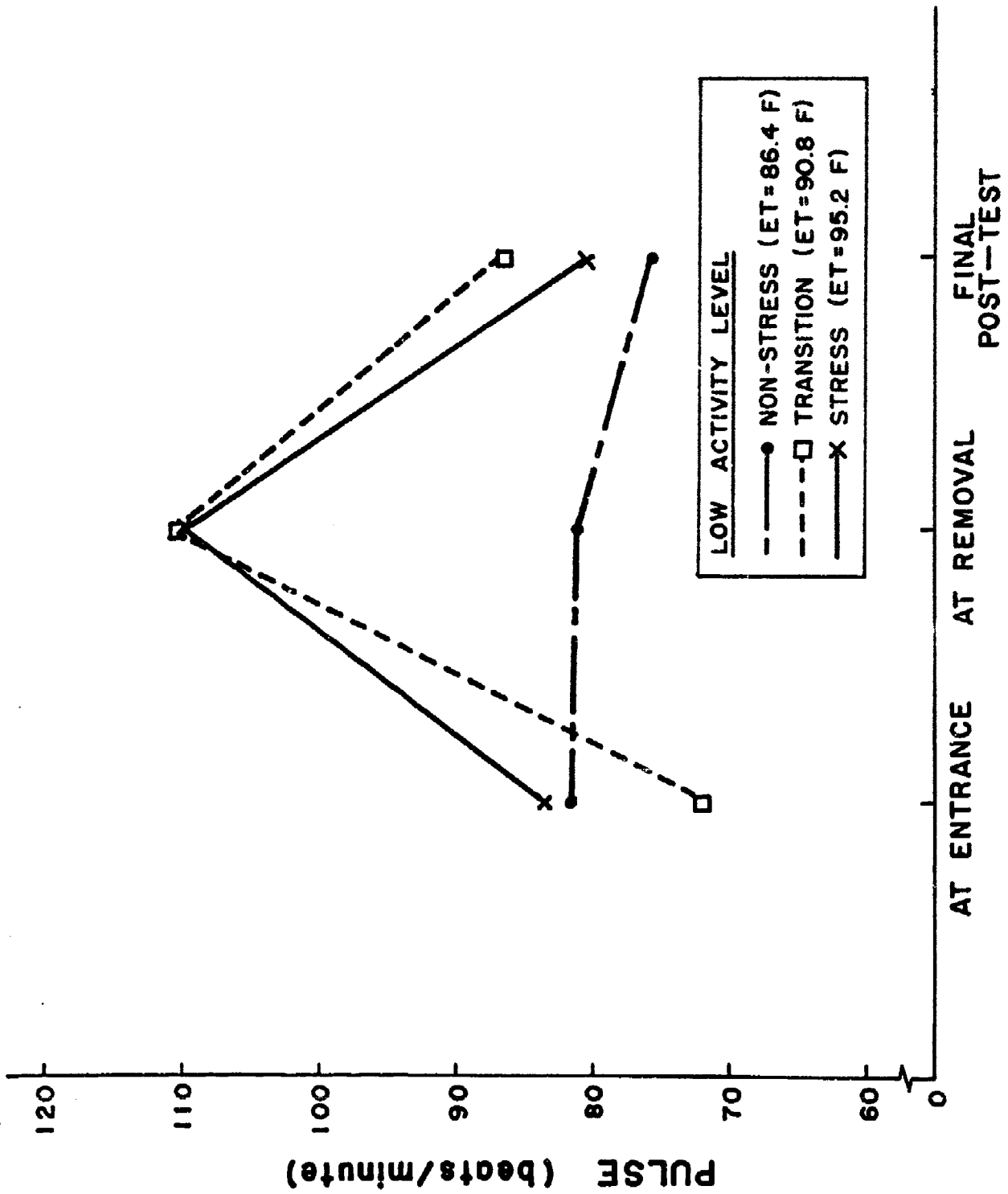
FIGURE 13 Mean Pulse Rates at Low Activity Level.
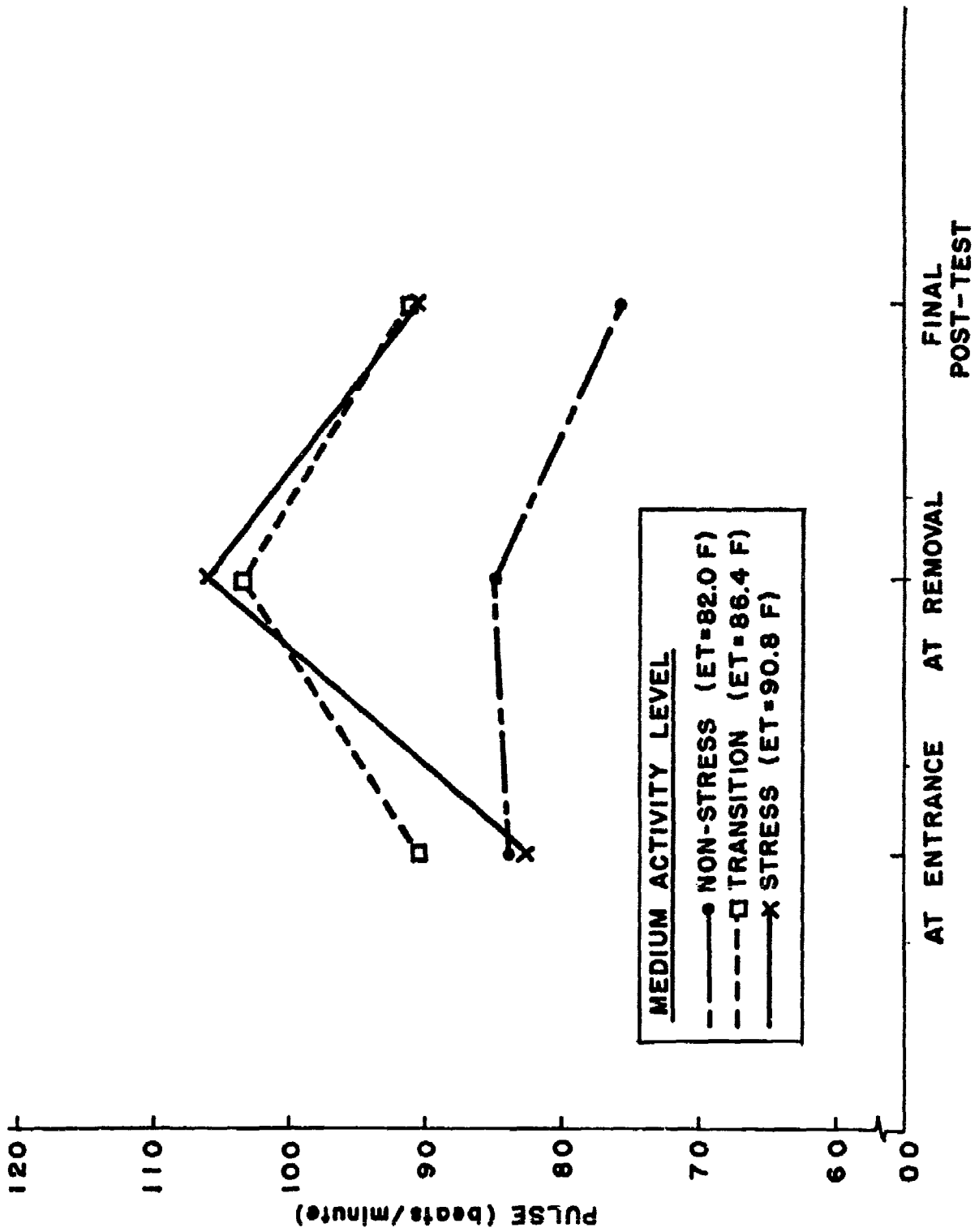
FIGURE 14 Mean Pulse Rates at Medium Activity Level.
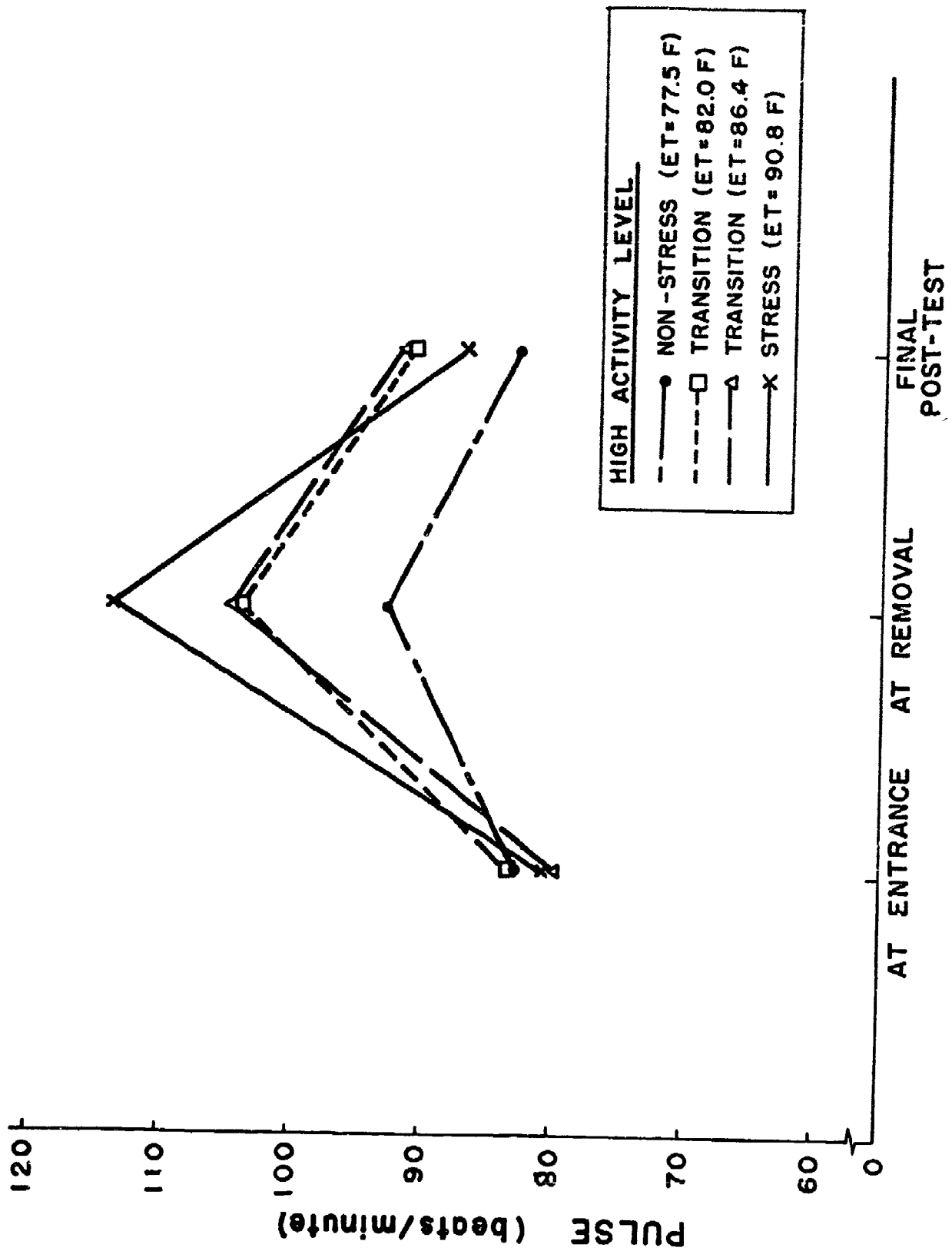
FIGURE 15 Mean Pulse Rates at High Activity Level.

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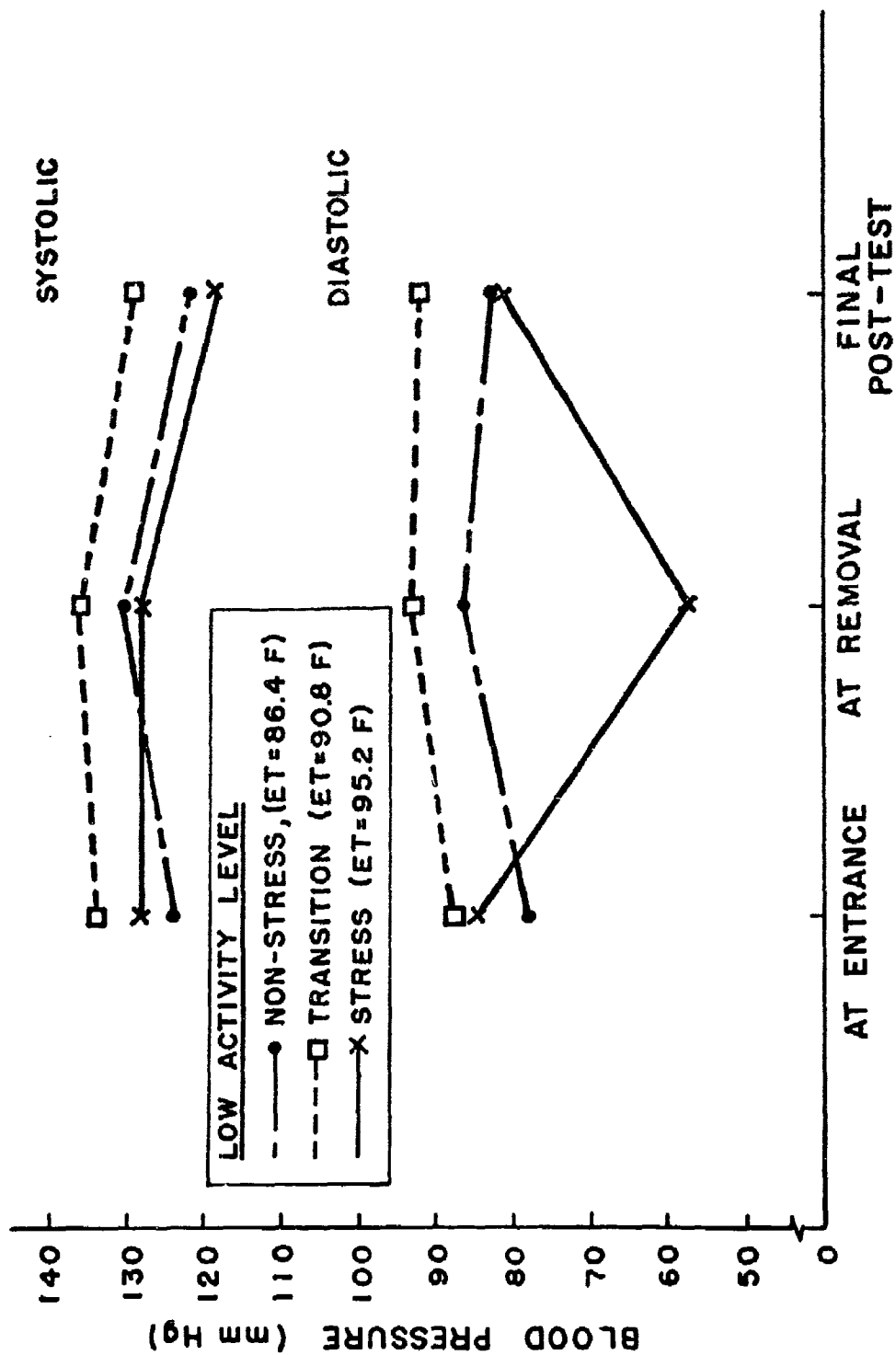
FIGURE 16 Mean Systolic and Diastolic Blood Pressures at a Low Activity Level

42
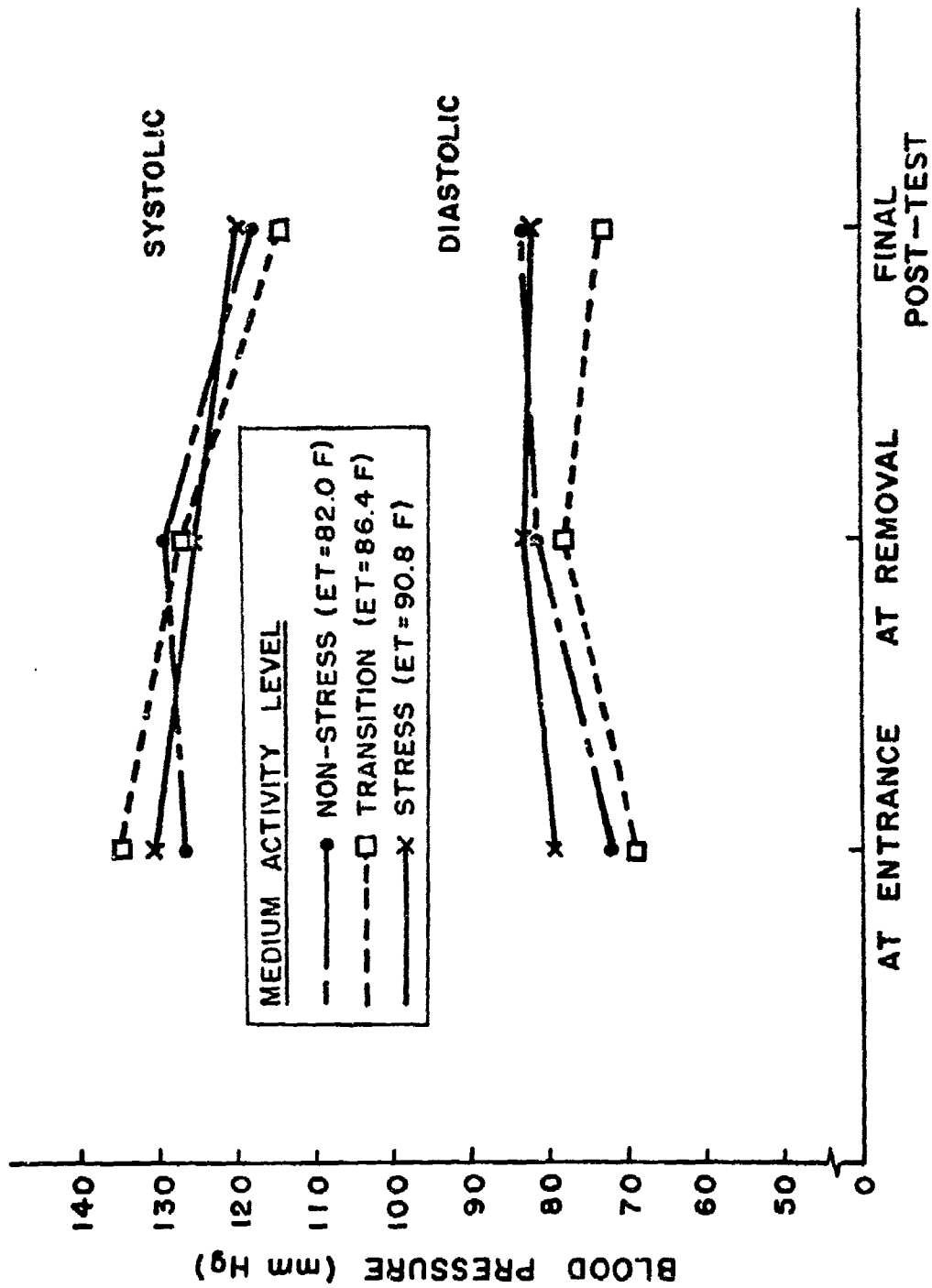
FIGURE 17 Mean Systolic and Diastolic Blood Pressure at Medium Activity Level.

43
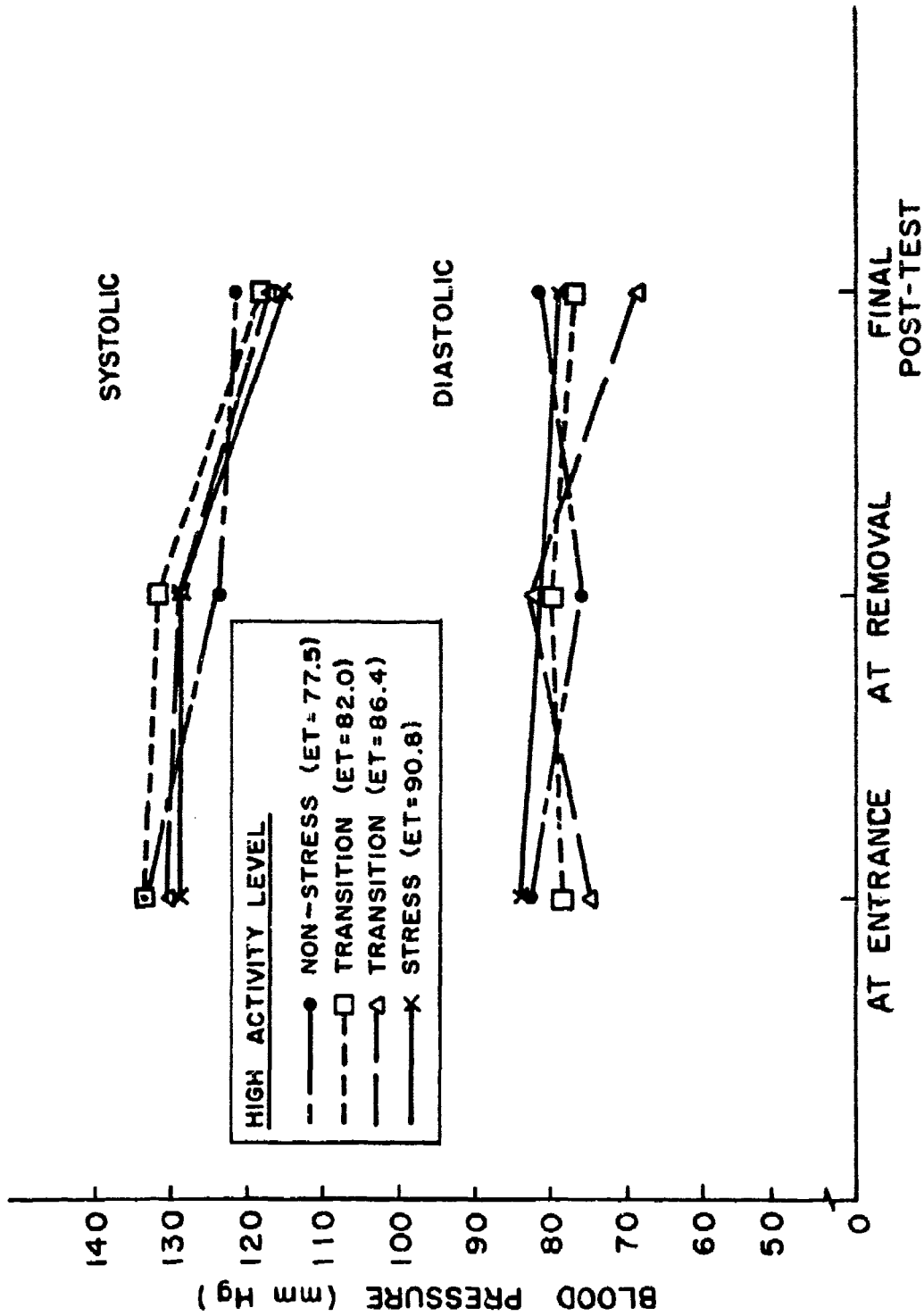
FIGURE 18 Mean Systolic and Diastolic Blood Pressures at High Activity Level.

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TABLE 5
Means and Standard Deviations* of Pulse Rate and Blood Pressure Measurements

| | PULSE RATE | | | BLOOD PRESSURE | | | | | |
| | | | | Systolic | | | Diastolic | | |
	At Entrance	At Removal	Final Post-Test	At Entrance	At Removal	Final Post-Test	At Entrance	At Removal	Final Post-Test
High Activity Level (0.15 hp/man)									
STRESS ET = 90.8 F	80 (8)	114 (17)	87 (11)	131 (9)	129 (13)	117 (10)	84 (8)	81 (12)	79 (9)
TRANSITION ET = 86.4 F	80 (11)	106 (16)	95 (7)	131 (8)	129 (15)	118 (16)	75 (8)	83 (5)	69 (13)
TRANSITION ET = 82.0 F	83 (14)	104 (17)	91 (20)	134 (13)	132 (18)	119 (12)	79 (6)	80 (8)	78 (6)
NON-STRESS ET = 77.5 F	83 (21)	93 (20)	83 (11)	134 (11)	124 (10)	122 (11)	83 (11)	76 (8)	82 (11)
Medium Activity Level (0.10 hp/man)									
STRESS ET = 90.8 F	83 (12)	106 (15)	91 (15)	130 (8)	126 (11)	120 (14)	80 (6)	83 (7)	82 (8)
TRANSITION ET = 86.4 F	90 (12)	103 (20)	89 (17)	136 (21)	127 (18)	114 (13)	69 (12)	78 (12)	73 (17)
NON-STRESS ET = 82 F	84 (12)	85 (15)	78 (13)	128 (14)	130 (11)	119 (8)	72 (14)	82 (9)	83 (10)
Low Activity Level (0.05 hp/man)									
STRESS ET = 95.2 F	84 (12)	110 (19)	80 (12)	128 (9)	128 (19)	118 (9)	85 (7)	51 (18)	81 (8)
TRANSITION ET = 90.8 F	75 (13)	111 (18)	87 (3)	134 (7)	136 (10)	129 (15)	88 (5)	94 (12)	92 (10)
NON-STRESS ET = 86.4 F	82 (12)	81 (10)	76 (6)	124 (9)	130 (11)	122 (9)	78 (10)	87 (10)	83 (8)

*Standard Deviation in parentheses.

to tolerate for a particular activity level is shown in Figure 7. This indicates that the non-stress and transition zones will allow generally the same magnitude of tolerance, the respective average exposure times are 8.0 and 6.5 hours. The stress zone provides a much shorter time for work in the shelter environment as the average exposure was approximately 1.8 hours.

As described previously, a 2F rise in rectal temperature was used as a primary criterion for removal of a subject from the test chamber. It can be found by inspection of the stress zones in Table 3 that the ratio of incidence of a 2 F rise to attainment of other stress criteria is 45:6. Of the six which reached other criteria, five were sick or too exhausted to maintain the work level. The sixth developed a weak knee condition. This can be interpreted as a measure of the reliability of a 2 F rise in body temperature to predict the on-set of thermal stress at the activity level and environments investigated. The recovery of a normal body temperature (which is presented in Report #1 under this contract and was similar in this study) within approximately one hour after removal from the stressful conditions indicates the moderate degree of thermal stress imposed.

As defined, the only difference between the establishment of a transition zone and a non-stress zone is that at least one subject reaches one of the stress criterion within the eight-hour test period. The most obvious factor in the deviation between predicted (Table 1) and observed (Table 2) non-stress zones is subject variability. Decreases in individual working efficiencies in some cases produces relatively higher metabolic rates which in turn would require higher heat exchange between the individual and the environment. The higher heat exchange required would have to be

accounted for by higher evaporative losses since air temperature and mean radiant temperature are fixed. This higher evaporative loss for some subjects often exceeds the maximum evaporative loss possible in the environment and allows for the storage of heat which results in a body temperature rise.

Refering to Table 4, actual sweat rates in the predicted non-stress zones are high enough to assume nearly 50% (4) wetting of the skin surface. Also the magnitudes of the sweat rates are such that if all the sweat were evaporated, the evaporative cooling often exceeds the maximum possible for that environment. This indicates metabolic rates that are relatively higher than predicted and results in heat storage. The existance of significant areas of wetted skin also allowed dripping of sweat and/or adsorption of sweat in clothes and towels which reduced the evaporative cooling effect per pound of sweat loss.

In Figure 12 rectal temperatures are plotted vs time at five minute intervals for three representative subjects. Two are examples of a condition where a 2 F rise was obtained causing the removal of the subjects from the test chamber. The third shows corresponding data for a subject who remained in the test chamber for the duration of the test. The first two show very similar trends even though the exposure times were quite different. In both cases, at the attainment of a 2 F rise, the temperature still was increasing at a significant rate (positive slope of the temperature profile) indicating the inability of the subjects to maintain a heat balance with the environment which resulted in excessive heat storage. In contrast to this, the third subject showed an initial rise of rectal temperature, followed by a subsequent leveling which indicated that the subject was maintaining a heat balance with the environment. These

figures are generally representative of the time-temperature profiles for all subjects with continuous data.

Note the individual differences in the subjects' basal rectal temperature shown in Figure 12 at the start of the tests. These BRT differences are typical, and suggest that the stress criterion of a 2 F rise above BRT for each subject measures individual stress more accurately than a stress criterion of a fixed rectal temperature, such as 102 F.

In a discussion of reliable thermal stress indices, there is disagreement about a definitive description of the human thermoregulatory system and its components. Unforturnately, this description is at this time not complete enough to explicitly define the location of thermoceptors in the body which have the express purpose of sensing thermal stress under all conditions. There are currently available at least two theories that describe a possible operation of the thermoregulatory system for working subjects. Minard and Copman (2) report Nielsen's explanation that increases in body temperature to an accurately controlled level are possible over a wide variation in environmental temperature for work levels of 200-700 BTU/hr. He feels that the rise in body temperature within limits is a function of work rate and should not be regarded as failure of or strain on the thermoregulatory system. He calls this evidence of a physiological control mechanism in that strong activation of the vasomotor and sweat mechanisms allows a heat balance to be maintained at the elevated body temperature. The same effect is noted in these tests when after the initial adjustment period to the exposure, if a subject's body temperature leveled off he was able to tolerate the exposure for the entire test period. However, in the case of a subject who was unable to maintain a heat balance with the environment, the heat storage continued and there was no leveling

off of the body temperature as shown in Figure 12.

Minard and Copman (2) also report that Benzinger feels rectal temperature is not a good indicator of stress as he has concluded that the hypothalmus is the control center for the thermoregulatory system and that temperatures measured at the tympanic membrane are better indicators of hypothalmic temperature. He contends the hypothalmus is effectively a thermostat for the human body and that the hypothalmus senses the temperature of the blood near it. In accordance with the difference between this temperature and the "set point" temperature within the hypothalmic "thermostat", thermoregulatory processes are brought into play to correct this difference. He has shown the direct correlation between change in tympanic temperature and change in sweat rates. However, the changes in tympanic temperature were the result of step or rapid changes in environment as Benzinger investigated them, and he found that rectal temperature did not respond as quickly as tympanic temperature. The trends in rectal and tympanic temperature were similar, however, and since these studies were conducted with constant environmental conditions the rectal temperatures would be expected to be reliable indicators of adjustment to the environment given longer times. Lind (3) states that the clinical judgement of experienced observers is the best method available for assessing limits of heat tolerance. In recognition of this possibility there was a registered nurse on duty at all times in the current study.

Since sweat rates are also accepted as good indicators (5) of stress level, Table 6 was prepared to show average sweat rates in the relative stress zones. It is noted from Figures 8 and 9 that the stress zone is well defined, as is shown in the tabulated mean values of Table 6. Also in Figures 8 and 9 the proximity of values in the transition zones to the

values in the non-stress zone shows good agreement with the predictions for the non-stress zones. An interesting result from Figure 9 is the uniformity of weight loss rates in the stress zone at different activity levels which indicates that this might be a simple, effective means of determining stress zones under these levels of activity for relatively short exposure times.

TABLE 6

Mean Values of Sweat Rate for Stress, Transition and Non-Stress Zones

Sweat Rate	Relative Stress Zone		
	Non-Stress	Transition	Stress
Percent of body weight/hr	0.43	0.68	1.25
Grams/meter^2-hour	168	258	480

According to Nielsen, as reported by Minard and Copman (2) and Blockley (4), a definite relationship is found between sweat rate and activity level. Figure 11 shows observed sweat rates vs. predicted metabolic rates (computed in Appendix D). "Best fit lines" are given for those points representing similar environmental conditions. The curves show similar reactions of sweat rate to work level for each environment. The marked increase of the level of sweat rate for the higher environmental temperatures indicates the greater thermal load handled by the sweating mechanism.

The P4SR (predicted four hour sweat rate), as defined by McArdie et al. and reported by Leithead and Lind (5) is a generally accepted predictor of stress imposed by a particular environment at a given activity. Table 7 shows the P4SR (5) and corresponding observed four-hour sweat rates (in liters). The observed four-hour sweat rates are computed as the product of mean surface area and mean hourly sweat rate multiplied by four. Grams of sweat were converted to liters by approximating the density of sweat as the density of water at 30 C.

TABLE 7

Predicted and Observed Four-Hour Sweat Rates in Liters

Relative Stress Zones		Activity Level		
		Low	Medium	High
Stress	0*	4.1	2.9	3.7
	P*	3.0	2.6	4.4
Transition	0	2.5	1.8	A. 1.7 B. 1.6
	P	1.2	1.5	A. 2.2 B. 1.6
Non-Stress	0	1.2	1.1	1.4
	P	0.7	1.0	1.2

*P = Predicted 4 hour sweat rate   A. DB = 90 F RH = 80% ET = 86.4 F
*0 = Observed 4 hour sweat rate   B. DB = 85 F RH = 80% ET = 82.0 F

The observed physiological strain (estimated by observed sweat rates) generally exceeds the predicted sweat rates. This is due in large part to the relatively larger subjects than "average" as can be seen in Table 4. Also the college-age male subjects probably were in better condition than the average man, therefore, higher sweat rates would be expected as predicted by Bass (6). The following values of realtive strain were computed as described by Humpheys et al. (7) for the stress zones of this test:

     a) relative strain = 2.2 at high activity level;

     b) relative strain = 1.6 at medium activity level;

     c) relative strain = 3.2 at low activity level.

The relative strain figures show the same order of stress imposed by the environment and activity level as do the observed sweat rates that are tabulated for the stress zones in Table 7.

Since consideration was given to the elimination of conditioning
of subjects who participated in several tests by allowing a subject to
participate in a test only twice a week, it was felt necessary to test
for any conditioning that may have occurred. To evaluate this, four sub-
jects who participated in the entire series of tests were tested at
the end of the series at the same activity level and environment* as
that at which they were tested originally. The average exposure time for
a 2 F rise of the four subjects for the early exposure was 2.5 hours compared
to an average time of 1.6 hours on the later exposure. These comparative
times indicate no significant conditioning.

One test was run with an activity level of approximately 0.18
horsepower per man due to an error in setting the PVK unit power level.
The environmental condition was DB = 85 F and RH = 80%. One subject was
removed after 3.5 hours due to a 2 F rise, the next team was removed
after five hours because of physical exhaustion and the two remaining
teams were removed after 7.75 hours due to physical exhaustion. Through-
out the test the subjects complained of leg fatigue and were unable to
maintain the pedal rate as the test progressed. The inability of the
subjects to maintain the work level while still not becoming thermally
stressed (only one subject with a 2 F rise) indicates that the activity
level was above the physiological capabilities of the subjects. This
indicates that attention must be given to maintaining work loads at
reasonable levels in shelter environments regardless of the thermal stress
imposed.

Leithead and Lind (5) state that wide variations of pulse rate are
found on initial exposures of unacclimatized subjects to elevated temper-
atures but variations are much reduced after acclimatization. Figures
13, 14 and 15 show mean pulse rates for all subjects with continuous data

*Stress zone - high activity level, 95 DB, 80% RH, 90.8 ET

for each test condition. The variations of pulse rates measured in these tests indicate in general that the subjects were essentially unacclimatized to the conditions.

In explaining cardiovascular responses to exercise in hot environments, Bass (6) reports that initial exposure causes expansion of the vascular bed with inadequate increase in blood volume. Erect posture and exercise exaggerate the deficiency in blood volume because of pooling and increased muscle blood flow. As a result, cardiovascular inadequacy, with subject distress and rapid pulse accompanies even moderate work in unacclimatized men. The characteristic hyperthermia, a result of impaired heat transfer from body core to the periphery, then is probably a secondary effect. However, the fact that hyperthermia does exist is of prime importance in evaluating thermal stress.

After the initial responses to exposure, Bass (6), Morehouse and Miller (8) relate that an increase in both pulse and stroke volume are expected with further exercise. There is expected some elevation in both systolic and diastolic pressures; however, diastolic responses are generally smaller in comparison. Figures 16, 17 and 18 show mean systolic and diastolic pressures for all subjects with complete data for each test condition The diastolic pressures remained at generally the same level throughout the exposures studied here, showing relatively little difference in stressful or non-stressful exposures. Post exercise systolic pressures were observed to be generally lower than pre-exercise pressures indicating a diminished stroke volume during the recovery period. Fit subjects will maintain essentially constant systolic pressure during exposure due to ability to maintain high cardiac output according to Morehouse and Miller (8) and this is generally observed in this study even in the case of stress zones.

Morehouse and Miller (8) relate that resting pulse may not actually
be true resting pulse since acceleration of heart beat often precedes
exercise, due to anticipatory reactions of the subject. Also, they
found that heart rate change with exercise is the same for fit as un-
fit subjects so that differences in pre-test pulse and pulse following
activity are a measure of the strain on the circulatory system for both
fit and unfit subjects. The mean increase in pulse rate above the pre-
test level in the stress zone for the high, medium and low activity levels
ware respectively 34, 21, 26. Morehouse and Miller (8) show increases
of pulse rate for corresponding work loads, at steady state are approxi-
mately 25, 23, 18. The present study was felt to impose a greater cardio-
vascular strain on the subjects than Morehouse and Miller's work, so the
larger values seem reasonable.

Pulse rates had a tendancy not to return to pre-test level even
after one hour of recovery. This is especially apparent in the medium
and high activity levels and in both stress and transition zones. How-
ever, the slightly increased rate after recovery was not excessive and
did not indicate severe stress on the subjects.

During the course of these studies the following observations were
felt to be of interest.

The PVK's used proved to be capable of providing continuous service
throughout all the tests (approximatley five 24-hour days) with a minimum
of maintenance. The greatest maintenance problem with the units was
the connecting joints for the modules. These joints allowed relative
movement between the modules and often caused the drive chains to be
thrown from the sprockets. The rear support legs on the modules were
easily bent under the weight of two riders and required straightening

periodically. The deformation was never severe enough to inhibit or restrict pedalling, however. The seats were reported to be uncomfortable by all subjects, and towels and foam pads were employed to overcome the discomfort from the bicycle seats. Almost all subjects rested their elbows on the handlebars, and these also needed padding for comfort. Since the subjects pedalled in athletic socks only, they all complained of foot discomfort as well. Whether ordinary shoes would be satisfactory was not e plored.

It is suggested that these items should be further investigated to eliminate these problems.

SUMMARY AND CONCLUSIONS

Thermal environments were established under this study which resulted in thermal stress in less than eight hours on healthy, college-age males working at three distinct, feasible levels of activity pedalling OCD bicycle ventilating kits on 15 minutes work, 15 minute rest cycle. The lower limits of the stress zones are as follows: 100 F DB and 80% RH (95.2 ET) at 0.05 horsepower per man, 95 F DB and 80% RH (90.8 F ET) at 0.10 horsepower per man, 95 F DB and 80% RH (90.8 F ET) at 0.15 horsepower per man.

Also established by this study were thermal environments which caused no significant amount of thermal stress within eight hours of exposure on healthy college-age males working as previously mentioned. The upper limits of the zones are as follows: 90 F DB and 80% RH (86.4 F ET) at 0.05 horsepower per man, 85 F DB and 80% RH (82.0 F ET) at 0.10 horsepower per man, 80 F DB and 80% RH (77.4 F ET) at 0.15 horsepower per man.

The environmental conditions at the three activity levels investigated between the stress and non-stress zones are termed transition zones, and are characterized by the ability of some subjects to remain unstressed after

an eight-hour exposure while other subjects were significantly stressed well before this time. Individual differences among subjects caused the width of the transition zone to be 9 F ET for the low and medium levels of activity and 13 F ET at the high level of activity.

In all cases the mean radiant temperature was controlled equal to the dry bulb temperature and the air velocity in the vicinity of the subjects was between 50 and 80 feet per minute.

APPENDIX A

EVALUATION OF INPUT
HORSEPOWER TO PVK

Discussion:

The input horsepower of the PVK was evaluated with a cradled dynamometer driving the sprocket on the rear module. The dynamometer was a d.c. motor mounted on pillow block bearings with an attached moment arm bearing on a balance scale to measure torque reaction. The rpm-static pressure values for each activity level were maintained with the PVK set up exactly as under test room conditions. Static pressure was controlled by adjustment of the dampers on the duct work and rpm was maintained by a variable d.c. pu. supply. Balance scale readings were taken for each activity level and the horsepower was established by

$$\text{horsepower} = \frac{2\pi Tn}{33,000}$$

n = rpm

T = $(W_1 - W_2)$M (ft.lb)

M = Moment arm length (feet)

W_1 = balance scale reading with dynamometer driving PVK (pounds)

W_2 = balance scale reading with dynamometer running free at same rpm (pounds)

By this method the friction loss in bearings was accounted for.

Results:

Low Activity Level:

Evaluation of Input Horsepower to PVK

$n = 35$ rpm   s.p. $= 0.255$ in. water

$M = 1.0$ feet

$W_2 = 1$ lb. 10 oz. $W_1 = 16$ lbs. 8 oz.

$T = 14.88$ ft-lbs.

Horsepower $= .102$

Medium Activity Level:

$n = 46$ rpm   s.p. $= 0.40$ in. water

$M = 1.0$ feet

$W_2 = 1$ lb. 10 oz. $W_1 = 23$ lbs. 12 oz.

$T = 22.13$ ft-lbs.

Horsepower $= 0.195$

High Activity Level:

$n = 53$ rpm   s.p. 0.57 in. water

$M = 1.0$ feet

$W_2 = 3$ lbs. 12 oz. $W_1 = 33$ lbs. 4 oz.

$T = 29.50$ ft-lbs

Horsepower $= 0.303$

58

APPENDIX B

MEASUREMENT OF INCIDENT AIR
FLOW ON TEST SUBJECTS

Discussion:

To determine if forced convection (air flow 50 fpm) was a
significant factor in the heat loss from the test subjects partici-
parting in the bicycle ventilation tests, air velocity measurements
in the general area of each subject were taken. The velocities were
obtained from a hot wire anemometer* with both bicycles operating to-
gether at each of the three activity levels tested. The test room
air supply fan was operating in all cases.

The air velocities were evaluated for the subjects resting in
the chairs provided, as well as for the subjects on the bicycles.
The anemometer probe was held at ankle height, waist height, and shoul-
der height of the subject in each area of the room investigated so as
to get a general view of the velocity profile around the test subject
in a particular area.

*Anemotherm Air Meter, Model 60, Anemostat Corporation

Results:

The following table presents the average magnitude of values of
incident air velocity on a test subject in a particular location at
a given activity level. See plan drawing of test room on the following
page for layout of seats and PVK arrangement.

Air Velocity (fpm)

Activity Level	Location				
	North Seats	Middle Seats	South Seats	North Bicycle	South Bicycle
High	50	55	75	55	75
Medium	65	55	65	60	65
Low	50	60	70	55	80

A few isolated incident air velocities at ankle height were comparatively excessive (e.g. 130, 180, 190, 400). These were measured in the areas near the inlet of the PVK fan.

Plan View of Test Room
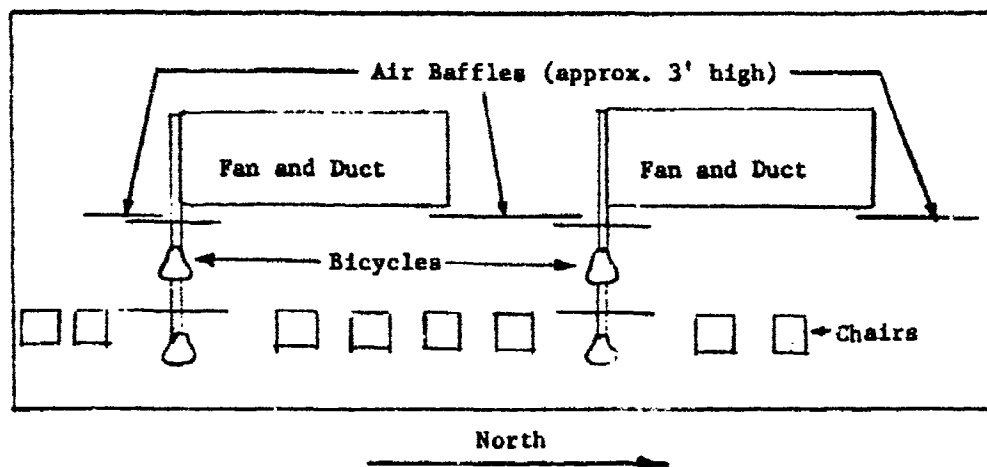
APPENDIX C

A uniform sack lunch menu for all the PVK tests consisted exclusively of sandwiches and potato chips. No canned foods were allowed in the lunches nor were any juicy foods of any type.

Sample sandwiches:

Lunchmeat

Tuna salad

Cheese

Hamburger

Submarine

APPENDIX D

Predicted Thermal Environmental Conditons for
the Zones of Stress, Non-Stress, and Transition

Assumptions:

1. Three work rates were used. These were nominally 0.15 hp,

    0.10 hp and 0.05 hp when working at pedaling the PVK one-

    half the time.

2. Efficiency of subjects at work = 20%

3. Average subject is 160 lbs, and has 20 square feet body area

4. Specific heat of subjects = 0.83 BTU/lb F.

5. The entire body mass will increase 2 F if the rectal temperature

    increases 2 F.

6. Mean skin temperature = 95 F.

7. Air velocity = 50 feet per minute

A. For the high work rate, the average subject's metabolism is

$$\frac{(0.15)(2545)}{0.2} = 1900 \text{ BTU/hour}$$

while resting his metabolism = 400 BTU/hour

Average Metabolism = $\frac{2300}{2}$ = 1150 BTU/hour

A 2 F rise in 8 hours would involve storage of heat in the

average subject of:

$$\frac{(2)(0.83)(160)}{8} = 33 \text{ BTU/hour}$$

Thus, the average heat loss for the subject working at the above rate,

if he were just to reach a 2 F rise in 8 hours (transition zone) would be

1150 - 33 = 1117 BTU/hour.

Let DB = 90, RH = 80%

From Reference 7, Figure 8, radiation and covection = 150 BTU/hour
and interpolating between Figure 11 and 12 the maximum evaporative
loss is approximately 1000 BTU/hour

Therefore, a Transition Zone is expected for the High Activity Level
at 90 F, 80%, and 50 ft/min air velocity.

Checking the conditions for a lower DB, namely, 85 F, from Figure 8,
radiation and convection = 350 BTU/hour. Then evaporation must be 1117 -
350 = 767 BTU/hour and interpolating between Figure 11 and 12, maximum
evaporation = 1400 BTU/hour.

Therefore, DB = 85 F, RH = 80% should be a Non-stress zone.

B. Medium Activity Level

The metabolism while working = $\frac{(0.10)(2545)}{.2}$ = 1270 BTU/hour

while resting = 400 BTU/hour

Average = $\frac{1670}{2}$ = 835 BTU/hour

2 F storage rate/8 hours = 33 BTU/hour

Net heat loss = 802 BTU/hour

Let conditions be DB = 95 F, RH = 80%, air velocity = 50 feet/minute

from Figure 8, radiation and convection = 0

Interpolating Figure 11 and 12, maximum evaporation loss = 650 BTU/hour

Therefore, DB = 95 F, RH = 80% is expected to be a Stress Zone.

As above, DB = 90 F, RH = 80% is expected to be a Non-Stress Zone.

C. Low Activity Level

The metabolism while working $\frac{(0.05)(2545)}{2}$ = 635 BTU/hour

Metabolism while resting = 400 BTU/hour

Average = $\frac{1035}{2}$ = 517 BTU/hour

2F storage/8 hours = 33 BTU/hour

Net necessary heat loss = 484 BTU/hour

Let DB = 95 F, RH = 80%, Velocity = 50 feet/minute

Radiation and Convection = 200 BTU/hour

Maximum Evaporation = 200 BTU/hour

DB = 100 F, RH = 80% is expected to be a Stress Zone, and

DB = 95 F, RH = 80% is expected to be a Non-Stress Zone.

APPENDIX E

Schedule of Tests

Date	Group	Effective Temperature (F)	Work Rate
June 21, 1966	1	90.8	.15 hp/man
June 27, 1966	2	82.0	.15 hp/man
June 23, 1966	1	86.4	.15 hp/man
June 24, 1966	2	77.5	.15 hp/man
June 27, 1966	1	90.8	.10 hp/man
June 28, 1966	2	86.4	.10 hp/man
June 30, 1966	2	82.0	.10 hp/man
July 6, 1966	1	82.0	.10 hp/man
July 8, 1966	1	95.2	.05 hp/man
July 11, 1966	2	90.8	.05 hp/man
July 12, 1966	1	86.4	.05 hp/man
July 13, 1966	2	86.4	.05 hp/man
July 14, 1966	1	77.5	.15 hp/man
July 15, 1966	2	95.2	.05 hp/man
July 18, 1966	2	90.8	.15 hp/man
July 19, 1966	1	90.8	.15 hp/man
July 20, 1966	2	90.8	.10 hp/man

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Water Consumption and Preference

During Exposure to Shelter Environments

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Water Consumption and Preference
During Exposure to Shelter Environments

INTRODUCTION

The hot, humid environments expected in Civil Defense shelters
will impose physiological stresses as well as psychological stresses
on the occupants. One of the most severe physiological stresses will
be the stress placed on the thermal regulatory mechanisms of the body.
Since evaporative heat loss or sweating provides the main avenue by
which the body loses heat, it necessarily follows that water must be
available to replace this loss. Otherwise, a state of dehydration
will result. Therefore, water stored in shelters must be of quality
and quantity sufficient for the survival of the occupants. The pur-
pose of this study was to determine the _ad libitum_ water consumption
of human subjects in simulated shelter environments, as a function
of the expected thermal environmental conditions and to determine
subject preference for stored or fresh (tap) water.

METHOD

Rationale

Because tests of this type require many subjects and extended
periods of time, they are costly. Accordingly, extensive planning
was utilized in the preliminary stages to provide the most meaningful
results consistant with the resources available. The information,
to be of maximum use, should be capable of extrapolation to the 14
day OCD occupancy limit and should use normal healthy subjects. This
section of the report presents the details of this planning and the
justification of the experimental design.

Duration of Tests

Each test was planned to last twenty-four hours. This period was
selected because of the circadian rhythmicity of the body temperature
and it was felt shorter tests would be of questionable value. Tests
longer than this would increase the cost and cause difficulty in
obtaining subjects. Calculations and literature searches, including
previous work under this contract, were used to predict the heat
transfer capabilities of human subjects, and these predictions
showed that extrapolation from 24 hours to several days should be
possible.

Subject Number and Selection

The subjects were high school or college students between the
ages of 17 and 26. They were given physical examinations, and those
with histories of heat exhaustion, cardiac difficulties, high blood
pressure, or who were on special diets or not in general good health
were eliminated. Eight subjects were used for each test. This
number could be reason..bly mananged in the KSU-ASHRAE Environmental
Test Chamber. Each group of 8 subjects was subjected to two tests
at the same environmental conditions, once with stored water and again
with fresh tap water. In this way, water preferences could be deter-
mined. Separate groups of 8 subjects were used for each environmental
condition. Figure 1 shows a general view of the test room. The ex-
periment provided 36 square feet per subject, and while this is consid-
erably above expected shelter densities, previous tests under this
contract (see phase 1 of this report) did not indicate significant effects
due to the crowding until 6 square feet per subject was reached. Even
then the effect was small. In addition, the mean radiant temperature

FIGURE 1   View of the KSU-ASHRAE environmental test chamber
during a test

was expected to be near skin temperature, so that heat loss would not be expected to be significantly affected by crowding.

The subjects were dressed in shorts, "cut-offs", or swim trunks and athletic socks. ' They were provided with turkish towels to wipe perspiration. Typical subjects are also shown in Figure 1.

Subject Activity

Sedentary activity was selected, including a sleeping period of approximately 8 hours. This would simulate anticipated shelter activity and would also conserve water and food; in addition, it would permit establishment of the highest thermal condition judged to be non-stressful unencumbered by the influence of activity.

Physiological Stress Limits

Limits on physiological measurements for the safety of the subjects were established on the basis of literature surveys and consultations with physicians. The criteria for removing a subject from the test environment for reasons of thermal stress are presented below; attainment of any one of these constituted evidence for removal:

1. <u>Oral Temperature</u> - A rise of 2 F above a stable, pretest level, called Basal Oral Temperature (BOT) in this report, for a period of ½ hour. If a subject's oral temperature was above 99 F during the pretest procedure, he was not allowed to participate in the tests.

2. <u>Physical Exhaustion</u>: Nurse's judgement

3. <u>Sick</u>: Nurse's judgement

The 2 F rise was established as one which was felt to be conservative for the subjects. Leithead and Lind (1) state "when the exposure is

relatively long, for example for an hour or more, then a rectal temp-
erature of about 39.2 C (102.5 F) has been considered a good indication
of a high degree of heat strain and that at or above this value some
men may be expected to find the conditions beyond their endurance".
Previous work under this contract has shown Basal Rectal Temperatures
(BRT) of normal, healthy subjects in a thermally neutral environment
(pretest room) ranged from approximately 99.0 F to 100.0 F. If the
subjects exhibit a 2 F rise in the core temperature, the level would
range from 101.0 F to 102.0 F. Therefore, the selection of a 2 F rise
rather than a specific core temperature level was felt to provide a
more meaningful evaluation of the environmental condition since each
subject was compared against his own basal temperature.

Physical and Physiological Measurements

For the purposes of extrapolation of the data to exposure periods
longer than 24 hours, sweat rates are particularly important. There-
fore, mass balances and body surface areas were calculated for each
subject. Each subject's initial weight and height were measured as
shown in Figure 2, and the amount of water and food consumed and excretia
were measured over the 24 hour period. Figure 3 shows the scale for
weighing food and excretia. The 24 hour urine output was collected
in labeled jars shown in Figure 4 and the specific gravity and sodium,
potassium and chloride levels were determined.

Because of the duration of the test, oral temperature rather
than rectal temperature was taken with a clinical thermometer every
½ hour while the subjects were awake and every hour while asleep unless
a subject experienced a rise of more than 1 F, and then they were taken
every ½ hour while asleep. If a 2 F rise was reached, the oral temp-

FIGURE 2   Monitor measuring subjects weight in pre-test room
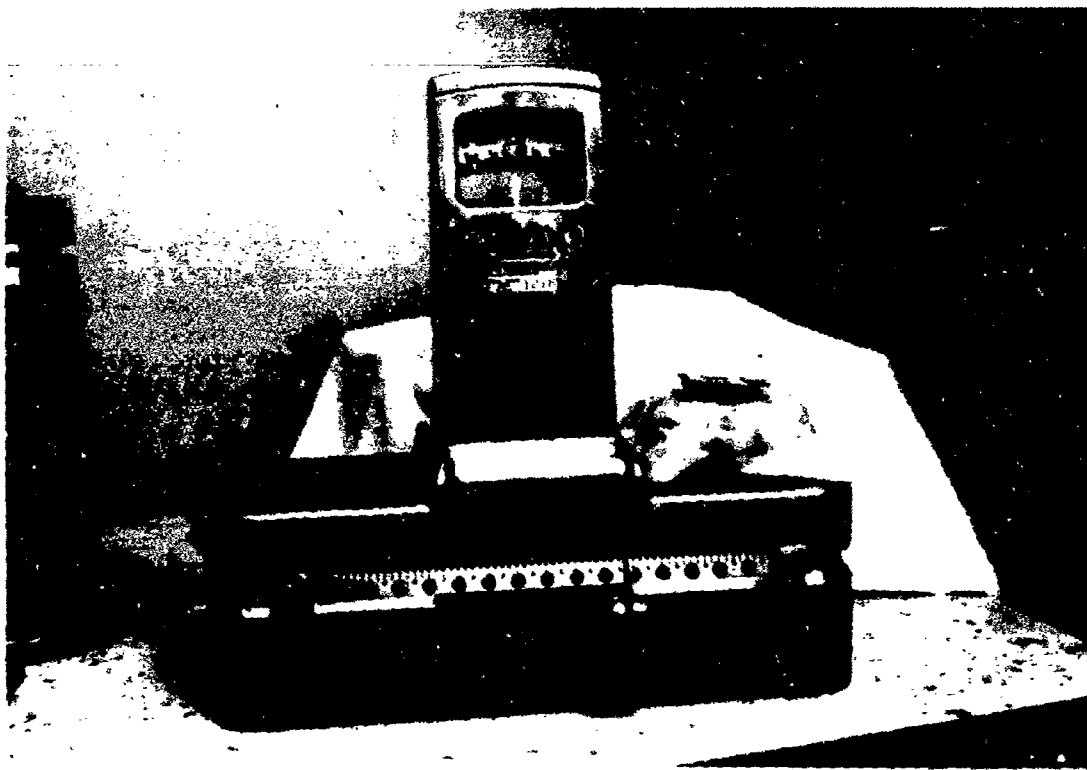
FIGURE 3 Balance scale used for weighing food and urine
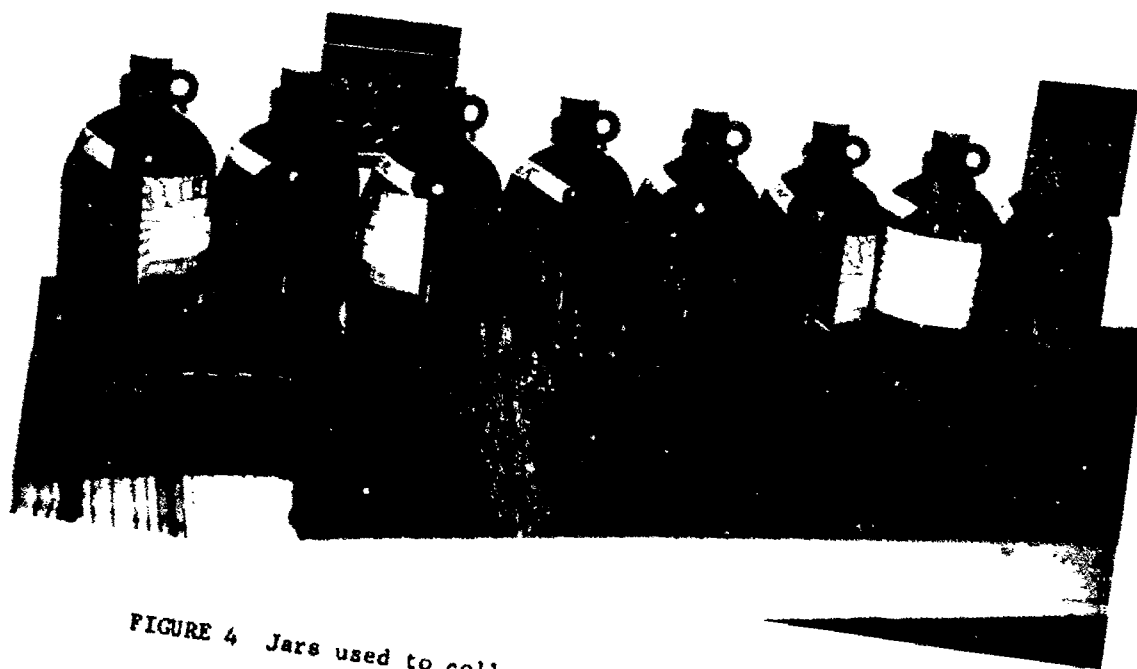
FIGURE 4   Jars used to collect each individual's urine for the 24 hours period

atures were taken every 10 minutes and the subject was removed ½ hour
after the 2 F rise was first observed; if this increment lasted less
than ½ hour, the subject remained in the test environment. Prior
experience had shown that with sedentary activities, the 2 F rise
almost always occurred before any other physiological limits were
reached so that blood pressure and pulse rates were not taken.

Water Selection

The stored water was obtained in Topeka, Kansas, because none
was available in Manhattan, Kansas. The water selected for use in
this study had been stored one year, and this was believed to be a
typically practical storage period. The stored water was prepared
by taking Topeka tap water, adding 2 ppm of chlorine and sealing it
in two separate polyethylene bags within a 17½ gallon drum, (Figure 5).
Before use in these tests, the water was tested for potability by
the Kansas State Department of Health Sanitation Engineering Labor-
atory, Bacteriology Section, Topeka, Kansas. (See Appendix A for
the test report on this water.) For fresh tap water, Manhattan,
Kansas, city water was used. Both types of water were dispensed to
the subjects ad lib. and at the temperature of the environment.

The groups of 8 subjects were randomly assigned an environmental
condition and informed that they were going to be given tap water
one day and stored water another day. They were not informed as to
the order of presentation or to the type of water they were drinking
on a given day. To minimize the effects of acclimatization on the water
intake of the subjects, sufficient time (usually one week) between
presentations was allowed. A random order of presentation of the
two waters was established. For two groups stored water was presented
first and for the third group fresh tap water was presented first.
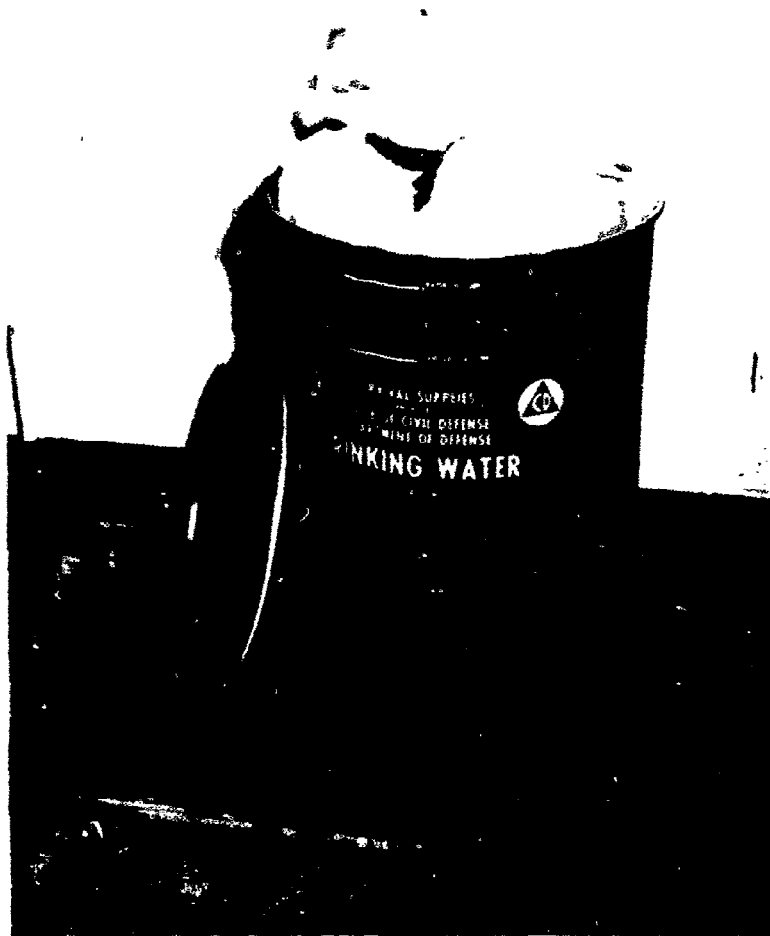
FIGURE 5   Office of Civil Defense drinking water storage
drum with sealed polyethylene bags

Thermal Environmental Conditions

The Office of Civil Defense recommends an upper limit of 82 Effective Temperature (ET) for shelter environments, whereas previous work under this contract showed 90.8 ET as a non-stress condition, except for 6 square feet per person crowding (see phase 1) for 8-hour exposures. OCD has specified the minimum quantity of water to be stored in shelters to be 14 quarts per person. Calculations (Appendix B) based on evaporation data for sedentary people of average size show that 1 quart per day per person would result in serious dehydration within 14 days which could possibly result in death at 85 ET (88.9 F Dry Bulb and 80% Relative Humidity) and above.

It was estimated that a 2 F rise in an 8 hour exposure would be approached at an ET of 90.8; further it was believed that this condition might be tolerated for longer times, since the body heat storage rate is only about 33 Btu/hr for a 2 F rise in 8 hours. Physiological changes might occur to limit further storage at this low rate. It was therefore, judged appropriate to attempt a 24-hour test at an ET of 90.8. ETs of 88, 85, and 82 were also chosen to determine the effect of temperature on the amount of water consumed as well as to provide a basis for statistical analysis. Eight 24-hour tests were then planned, two (one with each water), at each environmental condition 90.8 ET, 88 ET, 85 ET, and 82 ET. The relative humidity in all cases was chosen to be 80% since this was determined to be the most practical value, and previous work under this contract indicated good correlation of results with ET at various RHs. These conditions were controlled by a wet and dry bulb psychrometer in the test room shown in Figure 6 and the associated control equipment shown in Figure 7. The mean radiant temperature was maintained equal to the dry bulb temperature. Air velocities over the subjects were 30 fpm or less.
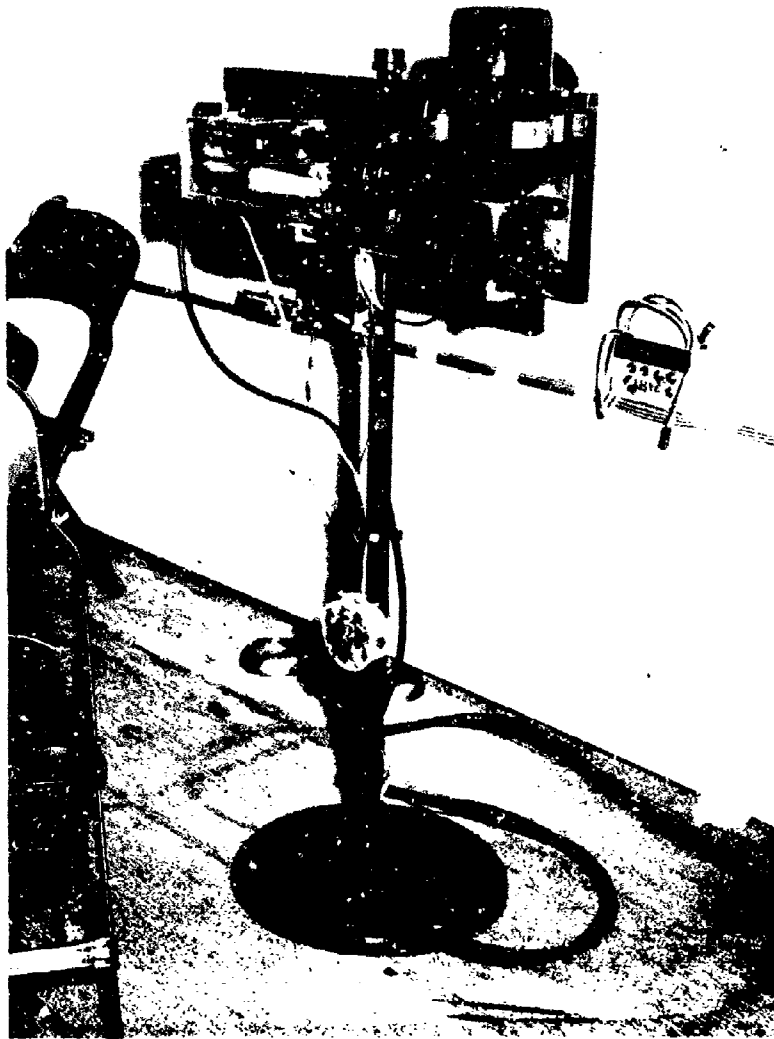
FIGURE 6 Wet and dry bulb psychrometer used to control
environmental conditions within the test chamber
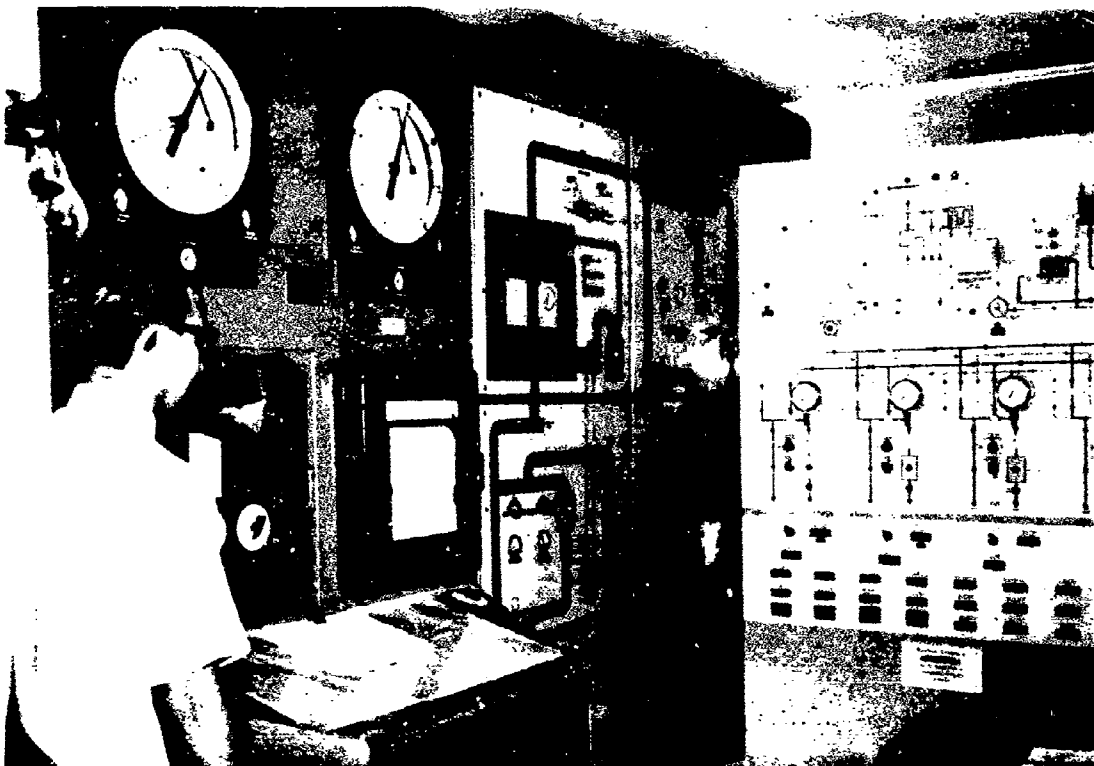
FIGURE 7   Control room for KSU-ASHRAE environmental facilities

The environmental room (see Figure 1) was fitted with 8 bunks,
2 card tables and 8 folding chairs. Bunk mattresses and pillows were
covered with polyethylene and cotton sheets and pillow cases were pro-
vided. Magazines and cards were available. A chemical toilet and
washstand were provided (see Figure 8). Although the toilet was never
used, a procedure for collecting and weighing feces was established
which could be used in longer tests. The water container, Figure 9,
was left in the room to maintain the water at room temperature. The
graduate shown was used to measure the water into individually labeled
covered cups with drinking straws for each subject.

PROCEDURE

The subjects reported to the pretest room at 0800 on the day of
the test and were asked to void and dress in shorts. They were asked
previously to live as normally as possible on the day before the test
and were instructed to have eaten breakfast before reporting. Whether
this was done in all cases is unknown. Appendix C gives the employment,
pretest and post-test information which they received about the test.
They were then weighed and their oral temperature was taken. At 0900
all eight subjects entered the test room, where they were assigned
to bunks and given water cups labeled with their names. They were free
to play cards, games, read, converse so long as the activity was sedentary.
They were permitted to read or sleep on their bunks. The nurse and/or
monitor obtained the data throughout the test, including the dispen-
sing and logging of the water consumed by each subject and the reading
of oral temperatures. Figure 10 illustrates this procedure. Also, each
subject recorded his own water consumption. Urine collection jars were
kept outside the test room and brought to the subjects at their request.
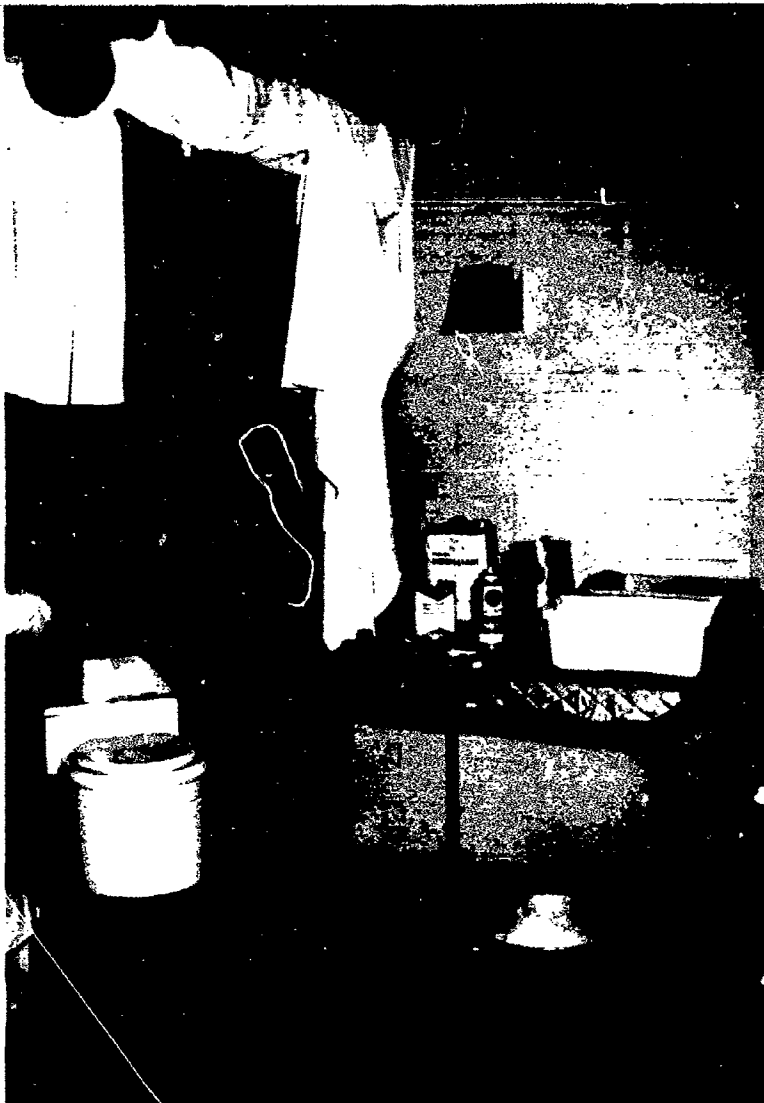
FIGURE 8   Chemical toilet and wash stand provided in the test
chamber
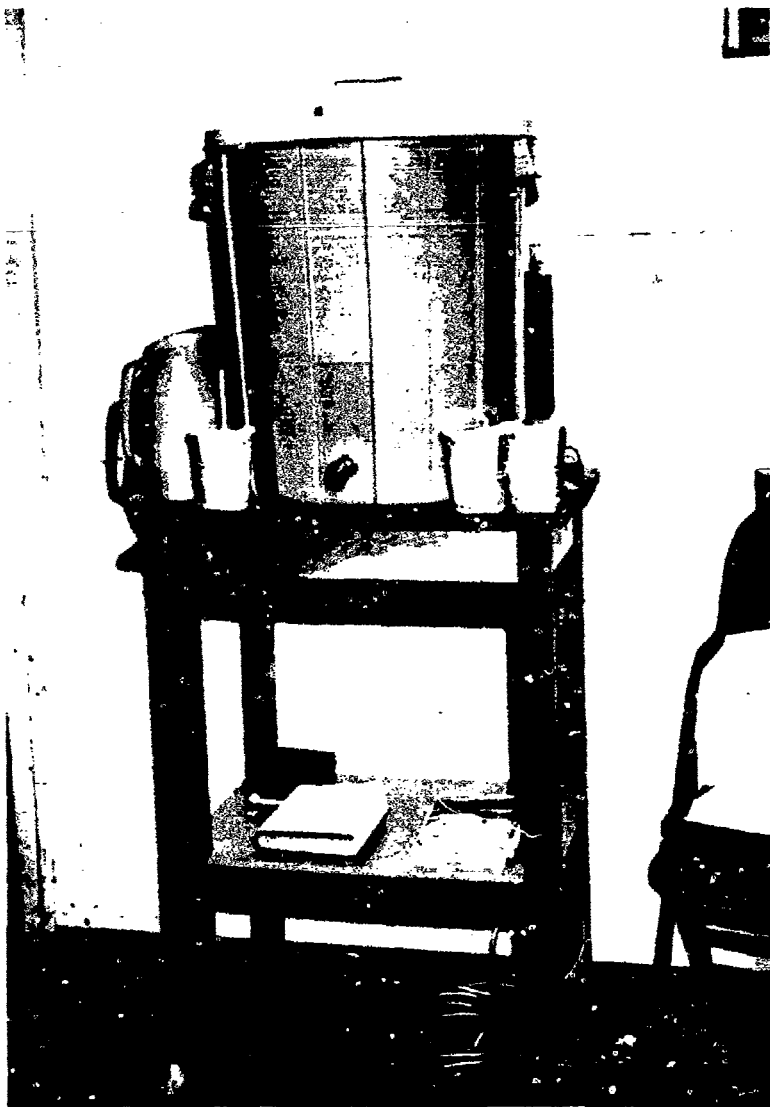
FIGURE 9 Water container, graduate, and cups used in the
dispensing and consumption of water

FIGURE 10   Nurse monitoring the subject's oral temperature at
½ hour intervals

The subjects selected their menus and meals were provided at 1200 and 1700. The limited box lunch menu, given in Appendix D, included no beverages, juicy fruits or salads. All food was weighed and the subjects placed all unconsumed food and napkins back in boxes for weighout. The water content of the food was not measured.

There was a "lights out" period from midnight to 0700 and oral temperatures were taken hourly through this period. The subjects were asked to void again before leaving the test. They then entered the pre-test room for weighout and temperature monitoring until their temperatures were within 1 F of BOT. Figure 11 shows this post-test monitoring procedure. After this, the subjects showered, dressed and were free to leave. They were not served breakfast.

During the test, if any subject experienced a 1.5 F rise he was asked to lie down, which tended to lower his temperature. In all cases except the test at 90.8 ET, no subject had to leave the test room for any reason. Temperatures were monitored with clinical thermometers selected at random. If unusual variations from previous readings were noted, another thermometer was randomly selected to verify the results.

All tests were conducted during the month of August, 1966.

RESULTS

Table 1 lists the mean age, physical dimensions, food intake, water intake, weight loss, sweat loss, urine excretion and an analysis of the specific gravity and electrolytic concentration of the urine for the subjects at each 24-hour test condition. The individual data are listed in Appendix E.

FIGURE 11 Nurse monitoring subjects oral temperature during
the post-test monitoring procedure

TABLE 1

SUMMARY OF RESULTS

Water Type	ET	N	Age (yr) Mean	S.D.	Height (in) Mean	S.D.	Weight (lb) Mean	S.D.	Body Surface Area (sq. m.) Mean	S.D.
Canned	82	8	21.1	2.8	70.53	2.08	171.41	19.83	1.969	0.113
	85	8	21.1	2.6	68.94	3.76	163.89	25.96	1.897	0.150
	88	8	19.9	3.8	70.34	3.04	177.86	28.32	1.996	0.180
Tap	82	8	21.1	2.8	70.53	2.08	170.58	17.86	1.965	0.107
	85	8	21.1	2.6	68.94	3.76	163.63	26.50	1.892	0.151
	88	8	19.9	3.8	70.34	3.04	177.69	27.42	1.995	0.176
		48	20.7		69.93		170.84		1.953	

Water Type	ET	N	Water Intake (lb/24 hr) Mean	S.D.	Food Intake (lb/24 hr) Mean	S.D.	Body Weight Loss (lb/24 hr) Mean	S.D.	% Body Weight Loss (lb/24 hr) Mean	S.D.	Sweat Loss (lb/24 hr) Mean	S.D.	Sweat Rate (gm/m²hr) Mean	S.D.
Canned	82	8	5.02	2.53	1.55	0.20	1.76	1.26	1.03	0.67	5.03	1.21	48	9
	85	8	6.39	1.44	1.69	0.24	1.24	1.64	0.78	0.99	6.49	0.65	65	7
	88	8	10.14	2.89	1.67	0.19	1.77	1.59	0.91	0.89	10.96	3.70	103	28
Tap	82	8	4.10	2.21	1.88	0.38	1.31	1.35	0.79	0.80	4.46	1.38	43	12
	85	8	5.48	0.96	1.59	0.24	1.15	1.30	0.71	0.75	5.98	0.64	50	6
	88	8	11.28	3.61	1.50	0.16	1.23	1.19	0.68	0.74	10.41	2.75	98	20

Water Type	ET	N	Urine Excretion (lb/24 hr) Mean	S.D.	Specific Gravity Urine Mean	S.D.	Na Urine (m.Eq/l) Mean	S.D.	K Urine (m.Eq/l) Mean	S.D.	Cl Urine (m.Eq/l) Mean	S.D.
Canned	82	8	3.25	1.92	1.021	0.006	194	39	47.6	24.4	133.7	25.5
	85	8	2.83	1.03	1.020	0.006	219	76	46.8	15.8	142.2	42.9
	88	8	2.75	0.81	1.020	0.007	150	58	51.8	21.1	109.2	27.2
Tap	82	8	2.82	0.71	1.020	0.004	181	50	44.4	16.8	111.2	33.4
	85	8	2.24	0.73	1.023	0.005	213	45	54.0	9.5	124.6	25.9
	88	8	3.61	3.09	1.022	0.009	119	29	78.4	55.2	77.9	39.4

TABLE 2

STATISTICAL ANALYSES OF VARIANCE OF THE RESULTS

WATER INTAKE

Source	Degrees of Freedom	Sum of Squares	Mean Square	F-Ratio
Temp. (T)	2	333.5750	166.7875	19.18*
Inds: Temp.	21	182.6605	8.6981	
Water type (D)	1	0.6604	0.6604	0.21
T x D	2	11.3372	5.6686	1.84
(Inds: Temp) x D	21	64.6108	3.0767	

SWEAT RATE

Temp. (T)	2	25370.76	12685.38	28.24*
Inds: Temp.	21	9431.52	449.12	
Water Type (D)	1	308.15	308.15	7.59*
T x D	2	0.26	0.13	0.03
(Inds: Temp) x D	21	852.94	40.62	

URINE EXCRETION

Temp. (T)	2	3.69965	1.84982	0.53
Inds: Temp.	21	72.84826	3.46896	
Water Type (D)	1	0.03101	0.03101	0.02
T x D	2	5.03381	2.51691	1.36
(Inds: Temp) x D	21	38.97528	1.85597	

PER CENT BODY WEIGHT LOSS

Temp. (T)	2	0.23865	0.11933	0.11
Inds: Temp.	21	21.99007	1.04289	
Water Type (D)	1	0.38341	0.38341	11.06*
T x D	2	0.06934	0.03467	0.12
(Inds: Temp) x D	21	5.90307	0.28110	

*Statistically significant at 5% probability level.

Four separate analyses of variance were computed to determine the effects of temperature (ET) and the type of water (stored or fresh) on water intake, urine excretion, percent of body weight loss, and sweat rate. The variance tables for these analyses are presented in Table 2.

The condition of 90.8 ET was defined as stressful in that all subjects reached a 2 F rise in oral temperature. The summary data for this condition are presented in Table 3 and the individual data are listed also in Appendix E. Most of these data are presented on a per hour basis since the subjects were removed from the test environment whenever they reached the 2 F criteria (7.75 to 12.67 hr.). An extrapolation of the water intake data to a period of 24 hour was made assuming that the water intake rate (lb/hr) would remain constant for all waking hours, and that no water would be consumed during the sleeping hours. These periods were 16 hours and 8 hours respectively. The extrapolation value of water intake per 24 hours was then found by multiplying the water intake per hour for each subject by 16 hours.

Table 4 shows the relationship between the mean water intake and Effective Temperature. This is a mean of the water intake for both types of water at each particular ET since the water intake was found to be independent of the type of water.

Table 5 shows the relationship between the mean absolute value of the 24 hour test period oral temperature variation and effective temperature. It is apparent that the variation decreases as ET increases.

DISCUSSION

The subjects averaged 20.7 years of age with a mean height of approximately 70 inches and a mean weight of approximately 171 pounds.

TABLE 3

SUMMARY OF RESULTS
STRESS ENVIRONMENT
Stored Water, ET = 90.8 F - 8 Subjects

Age (yr)		Height (in)		Weight (lb)		Body Surface Area (sq. m.)	
Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
19.9	3.8	70.34	3.04	178.08	27.78	1.996	0.136

Water Intake Rate (lb/hr)		Water Intake Extrapolated to 24 Hours (lb/24 hrs)		Body Weight Loss Rate (lb/hr)		Sweat Rate $(gm/hr.m^2)$		Time to Removal (hr)	
Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1.06	0.32	16.88	5.09	0.17	0.35	267	112	9.99	1.67

Specific Gravity Urine		Na Urine (m. Eq/1)		K Urine (m. Eq/1)		Cl Urine (m. Eq/1)	
Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1.020	0.009	67	41	71.5	26.3	70.2	33.0

TABLE 4

Mean water intake as a function of
Effective Temperature

ET (F)	Mean Water Intake (qt/man day)
82.0	2.2
85.0	2.8
88.0	5.1
90.8	8.1

TABLE 5

Mean absolute value of the 24 hour test
period oral temperature variation as a
function of Effective Temperature

ET (F)	Oral Temperature Variation (F)
82.0	2.15 ± 0.45
85.0	1.85 ± 0.37
88.0	1.65 ± 0.37

The mean body surface area was 1.953 square meters. The body surface area for each subject was estimated by the DuBois equation (2):

$$A = W^{0.425} \times H^{0.725} \times \frac{71.84}{10,000}$$

where:

A = surface area in square meters

W = weight in kilograms

H = height in centimeters

At the outset, it should be stated that none of the subjects reported a difference in the taste of the two types of water. Staff personnel judged the stored water to be acceptable, but somewhat "flatter" in taste than the fresh water. Therefore, it was believed the results would indicate that the water type was unrelated to water intake. This was proven empirically by the analyses of variance on the individual differences (Table 2) which indicated that the type of water has no significant influence on water intake or urine output. Furthermore, there was no interaction between Effective Temperature and the type of water for the four variables examined. As expected, (3), the water intake and sweat rate indicate a high correlation with Effective Temperature, however, no significance was found for the effect of Effective Temperature upon urine excretion or the percent of body weight loss.

Since there was no significant difference in water intake or urine excretion of the subjects tested with both stored water and fresh water, it would be reasonable to assume that no statistical difference would exist between sweat rate or percent body weight loss for the two types of water. However, this was not the case. As the analyses of variance indicate the sweat rate and the percent of body weight loss were significantly higher with stored water than with fresh water.
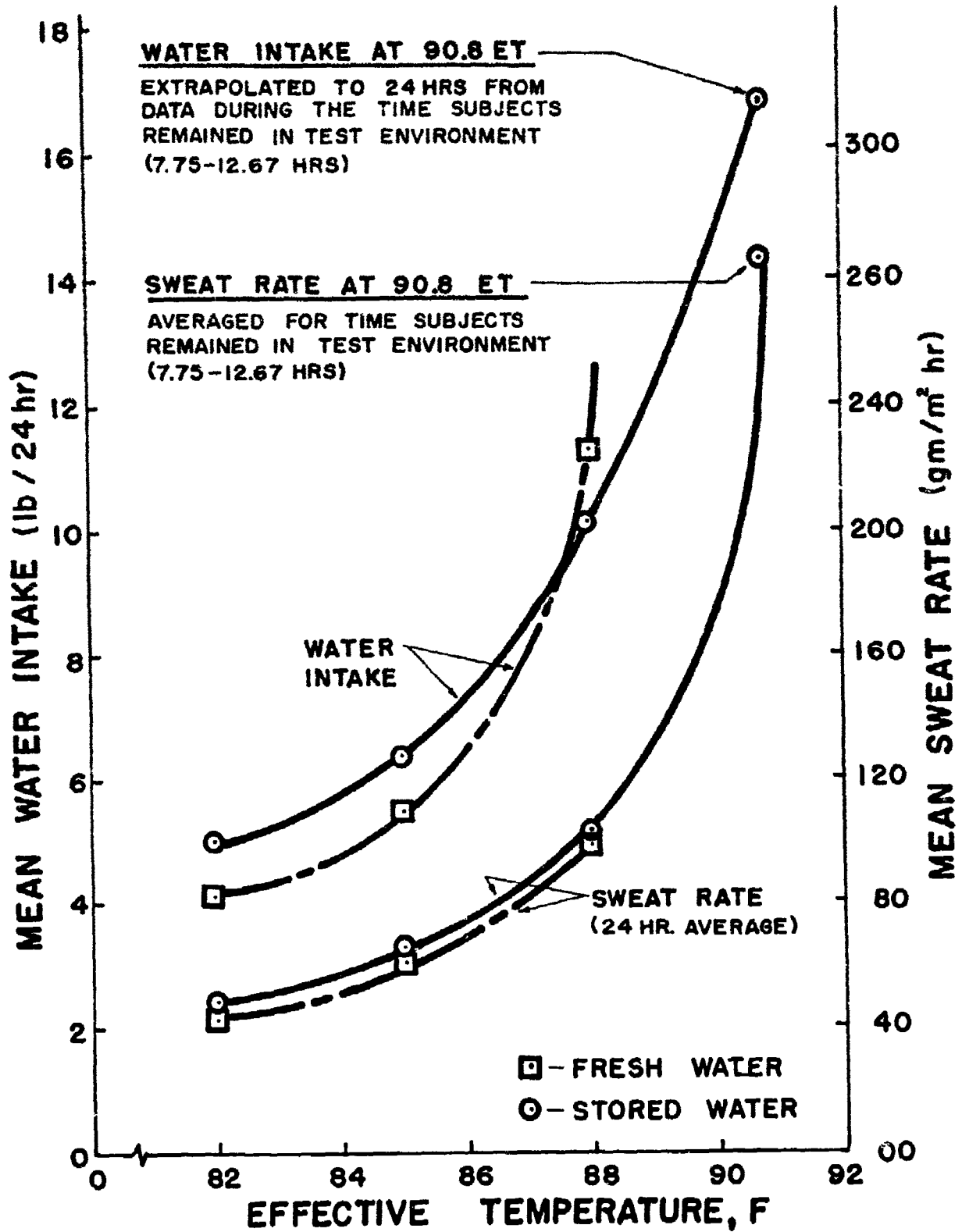
FIGURE 12 Mean water intake and mean sweat rate as a function of Effective Temperature
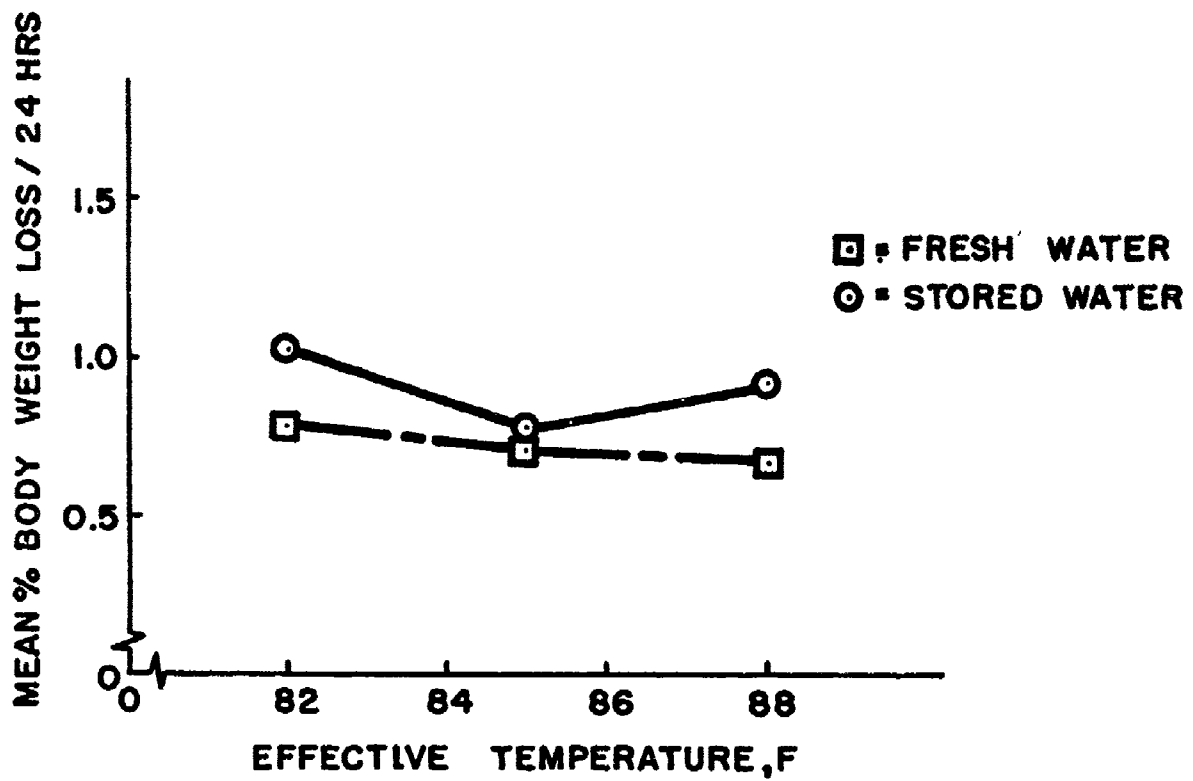
FIGURE 13 Mean per cent body weight loss per 24 hours as a function of Effective Temperature

This finding is difficult to explain but it would logically follow that if the sweat rate is greater for one type of water and yet the water intake is independent of the type of water, then the percent of body weight loss would also be greater. Figures 12 and 13 illustrate these relationships. The mean sweat rates are approximately 5% to 10% higher with the stored water (Figure 12) and the mean percent weight losses are 10%-20% higher with the stored water (Figure 13). The literature gives no indication that the type of water should effect sweat rates. Longer duration experiments might be expected to show no significance in these data. However, this result suggests the need for additional research to investigate this finding more thoroughly.

Figure 12 shows positive non-linear correlations between water intake and effective temperature, and between sweat rate and effective temperature. As effective temperature increases, water intake and sweat rates increase very rapidly above 85 ET. Table 4 indicates that at an ET of 82.0, the mean water intake for both types of water was approximately 4.56 lbs or 2.2 quarts per man day; at an ET of 85.0, it was 5.94 lbs or 2.8 quarts per man day; at an ET 88.0, it was 10.71 lbs or 5.1 quarts per man day; and at an ET of 90.8 the extrapolated rate was 16.88 pounds per 24 hours or 8.1 quarts per day. This suggests that an ET of 82.0, a drinking water allotment of 1 quart per person per day may be justified but for ETs above 82.0 this allotment would probably result in severe dehydration. Samuel (4) suggests that the water ration be increased to three quarts per man day. It is evident that longer duration tests are needed to validate the upper limit of ET where 1 quart per day drinking water allotment is adequate. Serious dehydration may result if the water loss of a subject exceeds 6% of

his initial weight (1). The mean sweat rates for the 82, 85, 88 and 90.8 ET conditions were approximately 25, 63, 101 and 267 gm/m^2hr respectively. It should be noted that the three lower mean sweat rates constituted an average for the 24-hour period while the highest sweat rate was an average for the time the subjects were in the test environment for the single test at 90.8 ET. The latter, therefore, does not include sweat loss while sleeping and undoubtedly the value is somewhat higher that would be the case if the test duration had been the planned 24 hours.

There was visible sweat and skin wetting on the subjects at all test conditions. Observation showed that as the ET increased the degree of skin wetting increased considerably. For reasons of subject comfort, towels were used to wipe off the unevaporated sweat at the subject's discretion. Therefore, not all the sweat was evaporated. Water loss from respiration was not measured independently but was included in the overall sweat rate.

Food intake was not related to Effective Temperature and the combinated food intake and water intake were insufficient to offset sweat losses and urine excretion. This is evidenced in a mean loss in body weight for all test conditions. This weight loss was attributed to: evaporation, wiping off sweat with towels, difference in weight of CO_2 expired and O_2 inspired (assumed negligible), urine excretion, respiratory water vapor loss, and skin loss. Skin loss as it affected weight was also considered negligible since it ranges from 0.0013 to 0.0066 lbs/man day (5) (6). There was no fecal excretion in any of the tests conducted. There were, however, five cases which showed a weight gain; this may be attributed to either a low urine excretion or

high water intake or both. The mean body weight losses ranged from 1.15 to 1.77 pounds, and were independent of effective temperature.

The standard deviations for both water intake and body weight loss were quite high. This was probably due to large variations in water and food intake, urine excretion and sweat rate among the subjects. The mean percent of body weight loss also showed high individual variations and ranged from 0.68%/24 hours to 1.03%/24 hours. The results do not indicate any definite correlation between percent of body weight loss and effective temperature. Longer duration tests might possible repudiate this finding as the literature suggests. Mean sweat loss was nearly equal to the mean water intake in each test. (See Table 1). It ranged from 4.46 lbs/24 hours with tap water and an ET of 82.0 to 10.96 lbs/24 hours with canned water at an ET of 88.0. No attempt was made to extrapolate the sweat loss to a 24 hour period for the incomplete 90.8 ET test because of the high variations among individuals and the unknown but reduced sweat losses during sleep.

Subject complaints of discomfort ranged from very slight discomfort at an ET of 82.0 to extreme discomfort, headache and nausea at an ET of 90.8. Dasler and Minard state that the American Institute of Research reported (3) headache and nausea occurred in pilot studies of short duration with ETs up to 86.0.

The urine collected from each subject was analyzed, specific gravity as well as sodium, potassium and chloride concentrations were measured (Table 1). The high concentrations of electrolytes suggests that the subjects were being stressed and were not fully acclimatized to the environment tested. The subjects would probably show smaller electrolyte concentrations after longer durations in order to prevent

heat exhaustion. As acclimatization takes place, these smaller concentrations would be brought about by aidosterone excretions in the adrenalin glands to retain the electrolytes in the body (1). Some people acclimatize much more rapidly than others so that the possibility of heat rash (3) and heat exhaustion in longer duration tests still exists for some subjects.

The mean urine excretion was independent of both the type of water and the ET. (Tables 1 & 2, Figure 14). The mean specific gravity was nearly constant at 1.020 for all environments and types of water, and was independent of the amount of water intake or urine excretion. Figure 15 shows mean levels of electrolyte concentrations for all test conditions. The mean potassium concentrations increased with each successively higher ET. Its level of concentration was less for stored water than for tap water. However, in general the mean sodium and chloride concentrations as well as the total electrolyte concentration decreased with increasing ET. The mean sodium, chloride, and the total urine electrolyte concentrations for stor·d water were slightly greater than for tap water. The data suggests that at an ET of 88.0 and above there may be an increased reabsorption of sodium and chloride in the kidney (1). If this were occurring then some acclimatization to heat was possibly occurring.

Representative oral temperatures for each test condition are shown in Figure 16. Increments in the mean oral temperatures from 0.7 F at 82.0 ET to 1.2 F at 88.0 ET were observed during the first two to four hours after entering the test room. The rate and magnitude of these increments increased with each succeedingly higher effective temperature. The oral temperatures became comparatively stable after
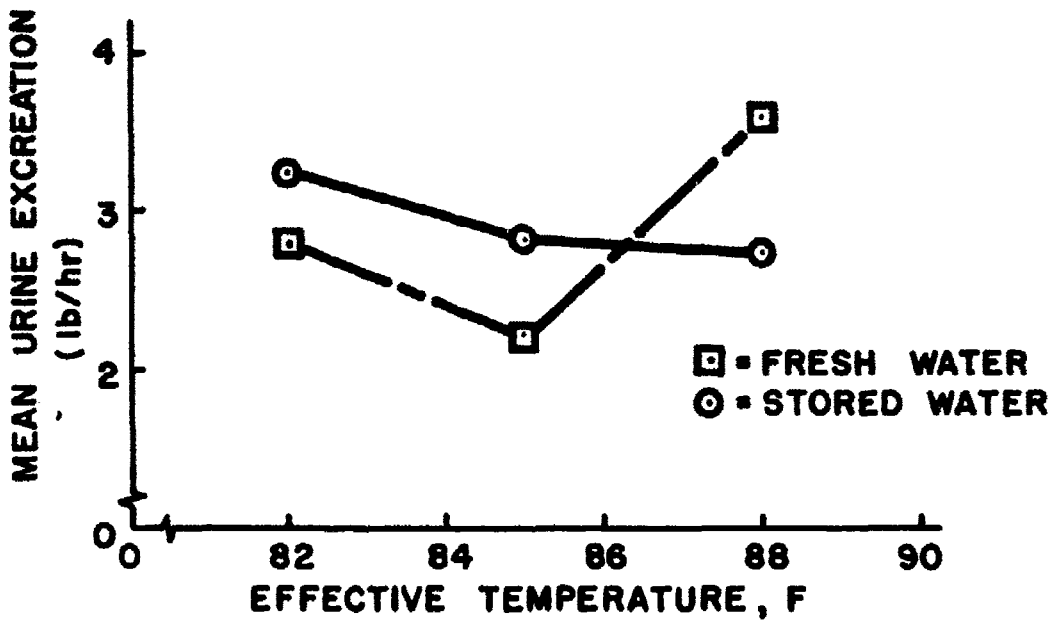
FIGURE 14 Mean urine excretion as a function of Effective Temperature
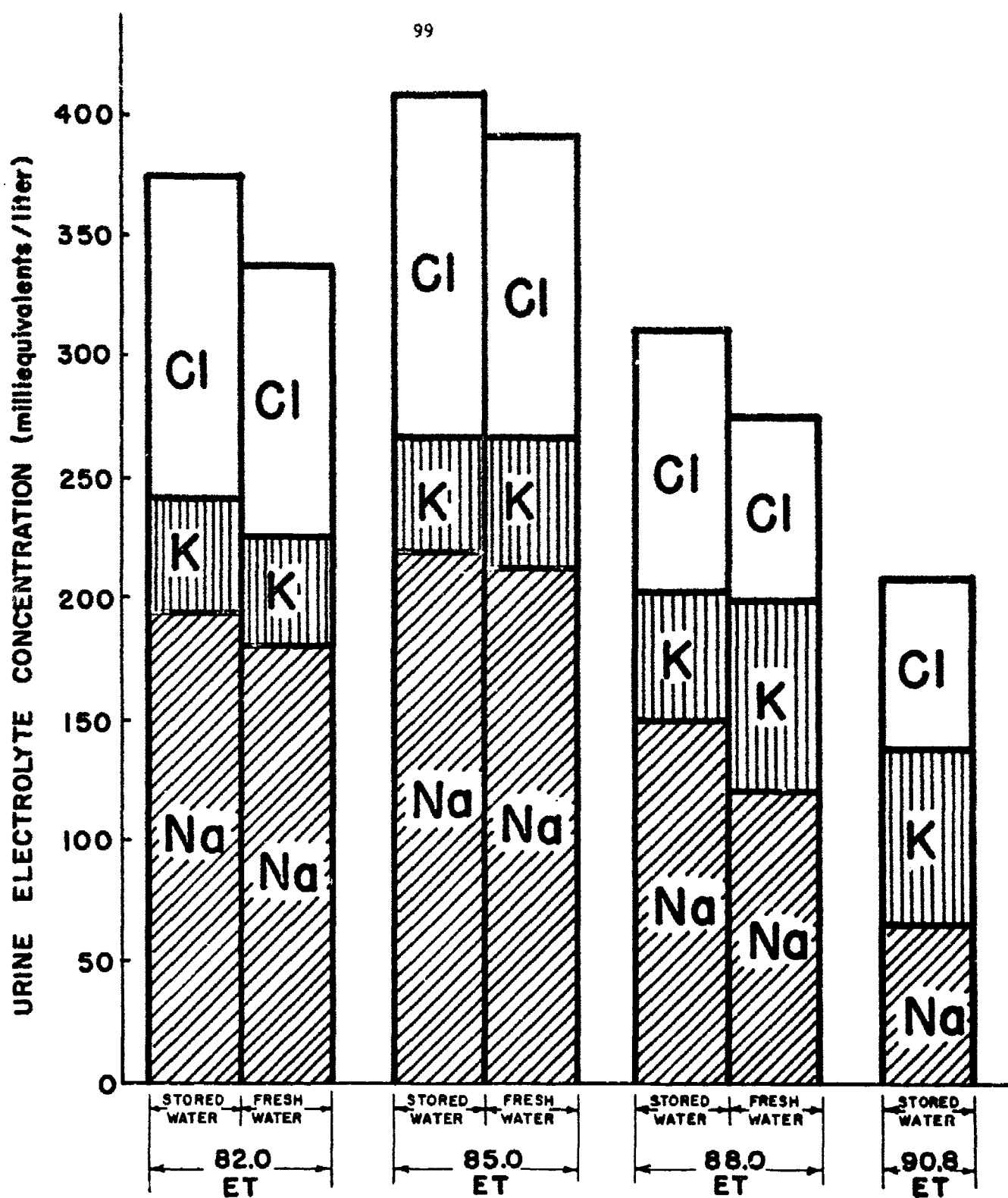
FIGURE 15   Urine electrolyte concentration (Na, K, Cl) as a
function of Effective Temperature
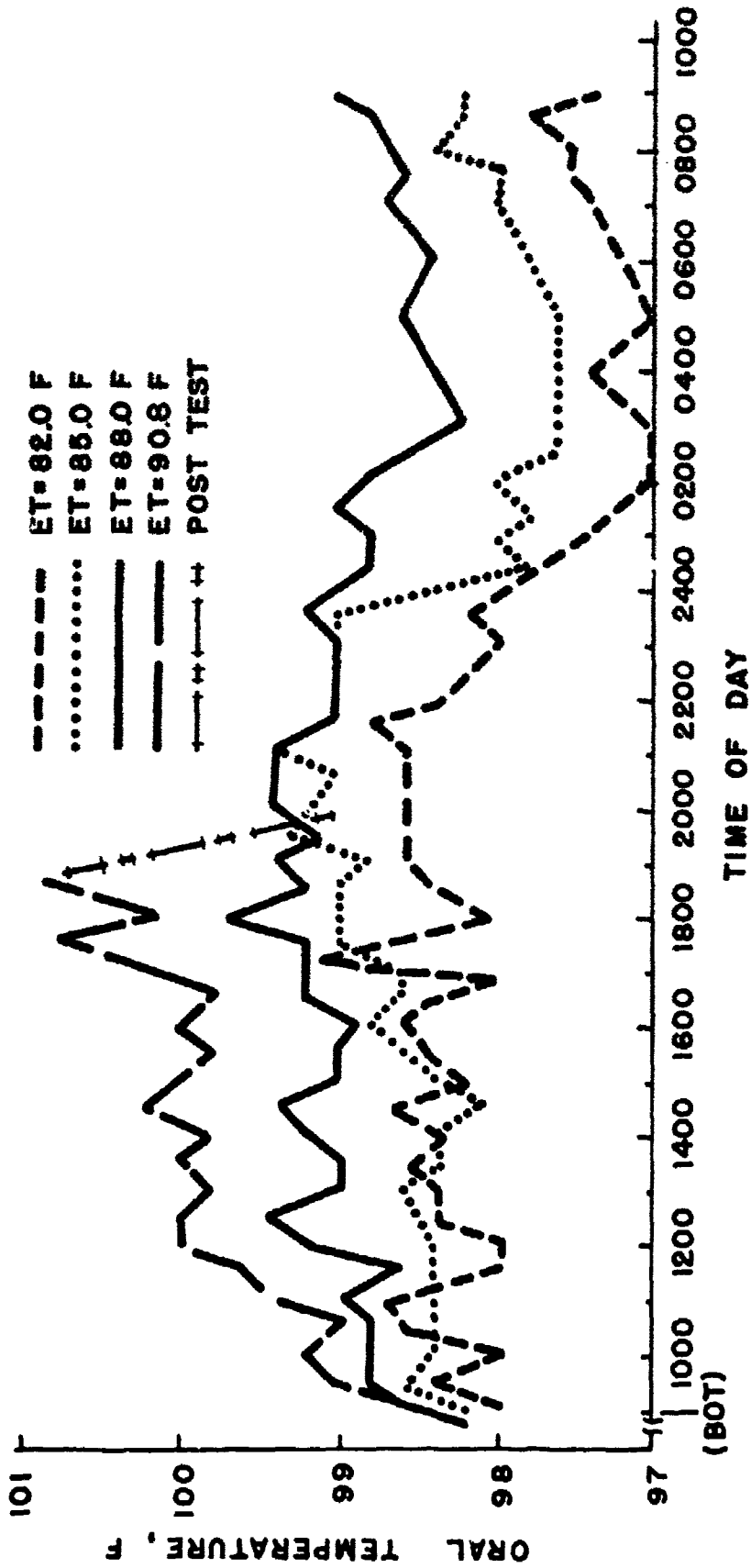
FIGURE 16 Representative oral temperatures as a function of
Effective Temperature and the time of day

this initial period and remained so until the subjects retired for the
night; an exception occurred at the 90.8 ET condition where the temp-
eratures continued to increase until a 2 F rise was reached. Dec-
rements in oral temperature were observed between 2300 and 0700 while
the subjects were sleeping. These decrements decreased as ET increased.
Upon awakening, the subjects again exhibited a rapid rise in oral
temperature. Table 5 shows that the mean absolute value of the 24
hour test period oral temperature variation decreased as ET increased.
This indicates that although the oral temperature reached higher
values with increasing ET the decrement in oral temperatures between
2300 and 0700 became much smaller as ET increased.

At the 90.8 ET condition, the mean time for a subject to reach
a 2 F rise was approximately 10 hours. It should be noted that the
first subject reached this criterion in 7.75 hours, and all other
subjects had been removed from the test condition by 12.67 hours.
This is in excellent agreement with the earlier work under this contract
(see report #1), which had found this condition to be nonstressful
for an exposure time of 8 hours with 8 subjects. However the results
indicate that 8 hours is not sufficiently long to establish body temp-
erature equilibrium at a value less than 2 F above basal.

SUMMARY AND CONCLUSION

Seven tests at four effective temperatures (82 F, 85 F, 88 F, 90.8 F) were conducted to investigate the acceptability of stored water (one year) and fresh water; in addition testing was conducted to determine the adequacy of the presently specified one quart per man per day drinking water ration. Subjects were college-age males who were exposed in groups of eight each - one for each type of water for two periods of 24 hours. An ET = 90.8 F was found to be stressful in that all subjects reached a 2 F rise in oral temperature, between 7.75 and 12.67 hours after entering the test chamber. Physiological measurements included urine excretion, its specific gravity and sodium, potassium and chloride concentration, oral temperature, sweat rates, per cent of body weight loss, water consumption, and food intake.

The results indicate that:

1.) Water intake and urine excretion were independent of the type of water. However, sweat rate and the per cent of body weight loss were a function of the type of water.

2.) The mean ad lib. water intake for all Effective Temperatures was always greater than the OCD specified allotment of one quart per man-day.

3.) Water intake and sweat rate were a function of Effective Temperature. While per cent of body weight loss and urine excretion were not a function of effective Temperature.

4.) The total electrolyte concentration decreased rapidly with Effective Temperatures above 85.0 even though the amount of urine excretion was independent of ET suggesting an increased reabsorption of sodium and

chloride in the kidney.

5.) In general oral temperature increased after entering the test environment. The rate of the increase and the increments were both greater for each succeedingly higher effective temperature. The mean absolute value of the 24 hour test period oral temperature variation decreased as ET increased.

6.) ETs above 88.0 definitely cannot be tolerated . periods of several days; ETs between 85.0 and 88.0 are probab. tolerable for several days but longer duration tests are needed to determine their feasibility more precisely and establish adequate water rations and physiological and psychological stress. ETs between 82.0 and 85.0 appear to be tolerable but longer durations tests (3) are also suggested to establish adequate water rations and investigate such problems as heat rash, acclimatization, etc.

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Bacteriology Section
801 Harrison
Topeka, Kansas

SPECIAL SAMPLES EXAMINATION REPORT

Date of Report _7-22-66_

TO: Pat Ryan, Dept. of Mechanical Engineering, Kansas State University

FROM: Marvin Dyck

Name of Body of Water: Containers of water in storage for Civil Defense

The samples of water herein reported were received from the person of _Pat Ryan_ on _July 20, 1966_ with laboratory examination beginning on _7-20-66_. The samples herein reported were collected by _Pat Ryan_ on _July 20, 1966._

Source of Sample	Special Sample Lab No.	Total Coliform per 100 ml	Fecal Coliform per 100 ml	Fecal Streptococcus per 100 ml
Drum #1 - Bottle # X8E	181	ng		
Drum #2 - Bottle # 5LY	182	ng		
Drum #3 - Bottle #5VU	183	ng		
Drum #4 - Bottle # 3WV	184	ng		
Drum #5 - Bottle # VF7	185	ng		
Drum #6 - Bottle # 95N	186	ng		

6-06-66

ng = no growth

Kansas State Department of Health
Sanitary Engineering Laboratory
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801 Harrison
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Source of Sample	Special Sample Lab No.	Total Coliform per 100 ml			Fecal Coliform per 100 ml			Fecal Streptococcus per 100 ml		
Drum #7 - Bottle no. 7RE	187	ng								
Drum #8 - Bottle no. 79L	188	ng								
(possible leak in bag)										
Drum #9 - Bottle no. 37an	189	ng								

6-06-66

ng = no growth

Appendix B

Predicted Evaporative Sweat Losses

The following calculations were made to establish the amount of evaporative sweat loss necessary to maintain a balance between the rate of metabolic heat production within the body and the rate of heat loss from the body to the surrounding environments. The calculations are based on the environmental conditions reported in the previous work of Humphreys et al (7).

The heat balance maintained between the body metabolism and the heat losses from the body are described by the equation

$$M-W = E \pm R \pm C_v \pm C_n \pm S$$

where

W = rate of functional work output from the body Btu/hr.

M = rate of metabolic heat production, Btu/hr.

E = rate of evaporative heat loss, Btu/hr.

R = rate of radiative heat loss or gain, Btu/hr.

C_v = rate of convective heat loss or gain, Btu/hr.

C_n = rate of conductive heat loss or gain, Btu/hr.

S = rate of heat storage within the body, resulting in a change in body temperature, Btu/hr.

Assuming the rate of heat storage, the functi nal work output, and the conductive heat loss to be zero, the evaporative loss becomes (E) = M - (R+C).

Burton (8) gives the following equation for sensible heat loss from the body: $R + C = 22.8 \dfrac{t_s - t_a}{I_c + I_a}$

$R + C$ = sensible heat loss from the average man, Btu/hr.

t_s = skin temperature, F

t_a = air temperature, F

I_c = insulation of clothing, clo

I_a = insulation of air, clo

A velocity profile of the test chamber indicated that 30 fpm is an excellent representative condition. The average subject was assumed to have a metabolic rate of 400 Btu/hr while sedentary and 300 Btu/hr while sleeping (10). The time durations for the states of activity were 16 hours and 8 hours respectively. As the subjects were dressed only in underwear and shorts, the calculations are based on nude values of skin temperatures and insulation. Based on the data and equations of Humphreys et al. (7), Burton (8) and Gagge et al. (9) the following calculations were performed.

Average man

Sedentary 16 hours @ 400 Btu/hr = 6400 Btu

Sleeping   8 hours @ 300 Btu/hr = 2400 Btu

Total   8800 Bt ay

1.) ET = 82.0 - 85.0F DB and 80% RH - 92.0 F skin temperature.

$$E = 8800 - \frac{22.8 \ (92.0 - 85.0)}{0 + 0.86} \times 24 \ hrs = 4340 \ Btu/day = 4.15^* \ lbs$$
evaporative sweat/day.

2.) ET = 85.0 - 88.4F DB and 80% RH - 94.0 F skin temperature.

$$E = 8800 - \frac{22.8 \ (94.0 - 88.4)}{0 + 0.86} \times 24 \ hrs = 5240 \ Btu/day - 5.01 \ lbs$$
evaporative sweat/day.

3.) ET = 88.0 - 91.8F DB and 80% RH - 95.0 F skin temperature.

$$E = 8800 - \frac{22.8 \ (95.0 - 91.8)}{0 + 0.86} \times 24 \ hrs = 6760 \ Btu/day = 6.48 \ lbs$$
evaporative sweat/day.

* Assuming a latent heat of vaporization for perspiration equal to that of water at skin temperature (approximately 1040 Btu/lb)

4.) ET = 90.8 - 95.0F DB and 80% RH - 95.0 F skin temperature

$$E = 8800 - \frac{22.8 \ (95.0 - 95.0)}{0 + 0.86} \times 24 \ hrs = 8800 \ Btu/day = 8.47 \ lbs$$
evaporative sweat/day

It should be noted that these values are the amount of evaporative sweat necessary to maintain a body heat balance and do not allow for any unevaporated moisture losses that will occur in excretion losses, or unevaporated sweat. In order to protect the subjects from serious dehydration, a total water loss from a shelteree of 6% of his initial weight in 14 days would be allowable. If sufficient food is available, this total loss may be assumed to be moisture loss rather than tissue loss. If the average male subject weighs about 170 lbs, a 6% water loss would be 10.2 lbs in 14 days or $\frac{10.2}{14}$ = 0.73 lb per day available body water loss, in addition to that taken into the body, less that excreted from the body. From the foregoing calculations, it is seen that even at an 82 ET, the total evaporative loss of about 4 lbs per day is not compensated by a water ration of one quart per day (or about 2 lbs/day). At this water ration, and an 82 ET, serious dehydration would be predicted.

Appendix C

I. Employment Instructions

All subjects should report 30 minutes prior to the time they are
to enter the test room to allow sufficient time to dress and record
necessary physiological data. The subjects should maintain a normal
daily activity on the day preceding the test; however, the alcohol
consumption should be minimal. Subjects should bring a pair of "cut-
offs" to the test and if it is necessary that they must withdraw from
participation, sufficient notice should be given the Insitute for
Environmental Research.

II. Pre-Test Instructions

Subjects will empty their bladders shortly before they are initially
weighed and again shortly before they leave the test environment and the
final weight is recorded. Each subject will be issued a water cup and
straw with his name on it. He should drink from his own cup only and
under no circumstances should he refill his cup, rather the refilling
should be performed by the monitor or nurse. The subjects will maintain
an individual tally sheet of the number of cups of water they drink to
compare with the tally sheet kept by the nurse and monitors.

The subjects will be assigned a bed upon entering the test room
and put on the sheets and pillow cases provided. The activity of the
subjects while in the test shall be relatively quiet, ie, playing cards,
reading, checkers, listening to stereo, resting, sleeping, etc. The
subjects will inform the monitor when they need to use the urine jars
or toilet.

III. Post Test Instructions

The subjects will have their final weight recorded immediately upon leaving the test room and entering the pre-test room. They are given a clean sheet in which to wrap themselves. Necessary post-test physiological data will be measured for approximately one hour, or until it is felt safe for the subject to leave. If the nurse observes a need for aspirin and/or salt tablets, they will be given. Also, if she feels that medical attention is needed, the subject will be sent to the Student Health Department for observation and checking by a physician. When the nurse feels the subject can safely leave, he will be paid and is free to shower, dress and leave.

Appendix D

Meal Menu
(List of Food subjects chose from)

Pizzaburger

Hamburger

Cheeseburger

French Fries

Chicken Dinner

Pork-Tenderloin Sandwich

APPENDIX E
INDIVIDUAL DATA

Date - August 8 & 9, 1966   Stored Water   DB = 85F, WB = 79.9F, RH = 80%, ET = 82.0F

Subject	Age (yr)	Ht. (in)	Wt. (lb)	Body Area (m²)	Water In. (lb/24hr)	Food In. (lb/24hr)	Urine Out. (lb/24hr)	Body Wt. Loss (lb/24hr)	Body Wt. Loss (%/24hr)	Sweat Loss (lb/24hr)	Sweat Loss (%/24hr)	Sweat Rate (gm/m²hr)	Sp.Gr.	Urine Na (millieq./liter)	K	Cl
T.D.	24	68.00	143.83	1.778	2.84	1.20	2.19	1.53	1.06	3.40	2.36	36	1.021	204	27.2	151.0
J.S.	24	69.00	162.70	1.894	4.54	1.54	2.11	1.35	0.83	4.55	2.80	45	1.025	260	79.2	220.5
F.C.	18	71.00	190.90	2.069	6.61	1.50	2.52	0.90	0.47	6.51	3.41	59	1.026	214	39.6	140.5
R.B.	23	68.50	198.37	2.049	6.62	1.50	3.22	1.37	0.69	6.34	3.20	58	1.013	152	25.6	91.5
R.F.	19	71.50	171.00	1.985	9.69	1.64	7.66	1.60	0.94	5.35	3.13	51	1.011	130	19.6	56.2
D.B.	23	74.25	185.79	2.113	3.52	1.45	4.12	4.79	2.58	5.67	3.05	51	1.020	190	41.6	125.4
J.A.	17	70.00	171.81	1.958	4.60	1.70	2.11	0.86	0.50	5.09	2.96	49	1.026	196	76.0	164.3
G.V.	21	72.00	146.89	1.870	1.76	1.89	2.04	1.69	1.15	3.31	2.25	33	1.026	202	72.0	120.0

Date - August 15 & 16, 1966   Tap Water   DB = 85F, WB = 79.9F, RH = 80%, ET = 82.0F

Subject	Age (yr)	Ht. (in)	Wt. (lb)	Body Area (m²)	Water In. (lb/24hr)	Food In. (lb/24hr)	Urine Out. (lb/24hr)	Body Wt. Loss (lb/24hr)	Body Wt. Loss (%/24hr)	Sweat Loss (lb/24hr)	Sweat Loss (%/24hr)	Sweat Rate (gm/m²hr)	Sp.Gr.	Urine Na (millieq./liter)	K	Cl
T.D.	24	68.00	143.36	1.776	2.03	1.19	1.92	0.66	0.46	1.96	1.37	21	1.023	210	29.6	103.8
J.S.	24	69.00	162.20	1.891	5.27	2.39	2.61	0.70	0.43	3.55	3.55	57	1.018	122	66.4	56.2
F.C.	18	71.00	191.70	2.073	7.93	2.02	3.05	-1.05	-0.55	5.85	3.05	53	1.020	212	28.0	121.1
R.B.	23	68.50	190.60	2.015	5.29	1.89	3.34	1.25	0.66	5.09	2.67	48	1.015	170	28.0	103.8
R.F.	19	71.50	171.50	1.987	3.52	1.91	4.12	2.89	1.69	4.20	2.45	40	1.014	130	36.8	86.5
J.A.	17	70.00	173.62	1.967	4.80	2.06	2.48	0.77	0.44	5.15	2.97	49	1.024	226	67.2	155.7
G.V.	21	72.00	149.66	1.855	0.88	2.11	2.95	2.84	1.90	2.88	1.92	29	1.023	250	42.4	155.7
D.B.	23	74.25	182.00	2.095	3.04	1.50	2.12	2.40	1.32	4.82	2.65	43	1.022	129	56.8	107.1

Date - August 10 & 11, 1966   Store Water   DB = 88.4F, WB = 83.1F, RH = 80%, ET = 85.0F

Subject	Age (yr)	Ht. (in)	Wt. (lb)	Body Area (m²)	Water In. (lb/24hr)	Food In. (lb/24hr)	Urine Out. (lb/24hr)	Body Wt. Loss (lb/24hr)	Body Wt. Loss (%/24hr)	Sweat Loss (lb/24hr)	Sweat Loss (%/24hr)	Sweat Rate (gm/m²hr)	Sp.Gr.	Urine Na	K	Cl (milliequiv./liter)
M.S.	23	67.50	126.60	1.675	5.72	1.70	2.23	1.20	0.95	6.39	5.05	72	1.020	290	50.1	186.0
B.P.	18	75.00	159.50	1.995	6.25	1.72	2.03	0.85	0.53	6.79	4.26	64	1.029	280	61.6	194.6
D.C.	23	71.75	185.10	2.058	4.41	1.56	2.78	2.70	1.46	5.89	3.18	54	1.017	131	56.8	99.4
F.B.	19	62.50	178.00	1.830	7.93	2.06	1.89	-1.85	-1.04	6.25	3.51	65	1.024	206	57.6	151.4
S.G.	21	68.25	208.16	2.086	6.17	1.80	1.98	1.51	0.73	7.50	3.60	68	1.020	266	48.0	142.7
B.Mc.	18	70.00	156.46	1.882	5.08	1.89	3.38	3.66	2.34	7.25	4.63	73	1.020	284	54.4	168.7
B.S.	22	66.25	139.06	1.720	6.76	1.33	3.45	1.56	1.12	6.20	4.46	68	1.016	210	30.9	125.5
G.S.	25	70.25	158.25	1.896	8.81	1.45	4.87	0.25	0.13	5.64	3.56	56	1.010	87	15.2	69.2

Date - August 17 & 18, 1966   Tap Water   DB = 88.4F, WB = 83.1F, RH = 80%, ET = 85.0F

Subject	Age (yr)	Ht. (in)	Wt. (lb)	Body Area (m²)	Water In. (lb/24hr)	Food In. (lb/24hr)	Urine Out. (lb/24hr)	Body Wt. Loss (lb/24hr)	Body Wt. Loss (%/24hr)	Sweat Loss (lb/24hr)	Sweat Loss (%/24hr)	Sweat Rate (gm/m²hr)	Sp.Gr.	Urine Na	K	Cl (milliequiv./liter)
M.S.	23	67.50	125.06	1.667	5.25	1.47	1.47	0.46	0.37	5.71	4.57	65	1.030	260	58.4	155.7
B.P.	18	75.00	159.24	1.994	5.29	1.73	2.26	0.59	0.37	5.35	3.36	51	1.027	234	69.2	138.4
D.C.	23	71.75	186.29	2.064	3.70	1.48	2.81	3.79	2.03	6.16	3.31	56	1.019	240	56.0	134.0
F.B.	19	62.50	179.43	1.836	7.05	1.95	2.39	-0.22	-0.12	6.39	3.56	66	1.023	190	54.4	129.8
S.G.	21	68.25	207.53	2.084	6.17	1.34	1.19	0.83	0.40	7.15	3.45	65	1.027	250	43.2	116.8
B.Mc.	18	70.00	155.47	1.877	5.23	1.91	2.55	1.47	0.95	6.06	3.90	61	1.024	230	53.6	142.7
B.S.	22	66.25	139.65	1.720	5.82	1.41	3.42	2.15	1.55	5.96	4.29	65	1.014	130	38.4	72.5
G.S.	25	70.25	157.00	1.890	5.29	1.44	1.80	0.16	0.10	5.09	3.24	51	1.022	168	58.4	107.1

Date   August 19 & 20, 1966   Tap Water   DB = 91.8F, WB = 86.3F, RH = 80%, ET = 88.0F

Subject	Age (yr)	Ht. (in)	Wt. (lb)	Body Area (m²)	Water In (lb/24hr)	Food In (lb/24hr)	Urine Out (lb/24hr)	Body Wt. Loss (lb/24hr)	Body Wt. Loss (%/24hr)	Sweat Loss (lb/24hr)	Sweat Loss (%/24hr)	Sweat Rate (gm/m²hr)	Sp.Gr.	Urine Na (milli-q./liter)	K	Cl
T.W.	17	72.00	170.42	1.992	9.69	1.27	1.81	0.73	0.43	9.88	5.80	94	1.035	50	105.6	56.2
J.H.	24	71.50	176.64	2.012	8.79	1.36	2.16	0.64	0.36	8.63	3.19	81	1.023	214	97.6	108.1
J.W.	26	69.50	173.93	1.959	13.22	1.61	5.69	0.77	0.44	9.91	5.70	96	1.016	58	18.4	43.3
G.B.	17	67.75	151.45	1.813	7.77	1.81	2.66	3.17	2.09	10.09	6.66	105	1.026	254	66.7	142.7
B.J.	17	73.00	201.45	2.160	12.04	1.45	1.94	2.51	1.25	14.06	6.98	123	1.023	21	188.4	39.0
G.C.	23	68.00	215.00	2.110	17.60	1.48	10.52	0.67	0.31	9.23	4.29	83	1.005	34	13.6	36.7
H.R.	18	66.00	132.41	1.680	7.05	1.52	1.48	-0.50	-0.38	6.59	4.98	74	1.026	204	63.2	103.8
G.W.	17	75.00	200.20	2.197	14.08	1.52	2.61	1.87	0.93	14.86	7.42	128	1.024	119	73.6	93.0

Date - August 22 & 23, 1966   Stored Water   DB = 91.8F, WB = 86.3F, RH - 80%, ET = 88.0F

Subject	Age (yr)	Ht. (in)	Wt. (lb)	Body Area (m²)	Water In (lb/24hr)	Food In (lb/24hr)	Urine Out (lb/24hr)	Body Wt. Loss (lb/24hr)	Body Wt. Loss (%/24hr)	Sweat Loss (lb/24hr)	Sweat Loss (%/24hr)	Sweat Rate (gm/m²hr)	Sp.Gr.	Urine Na (milli-q./liter)	K	Cl
T.W.	17	72.00	173.19	2.006	8.81	1.70	2.87	2.38	1.37	10.02	5.79	94	1.025	224	49.6	139.8
J.H.	24	71.50	176.69	2.013	7.70	1.58	2.68	1.18	0.67	7.78	4.40	73	1.022	174	57.6	133.0
J.W.	26	69.50	173.22	1.955	10.57	1.58	4.38	1.93	1.11	9.70	5.60	94	1.009	48	27.2	64.8
G.B.	17	67.75	150.80	1.809	7.51	1.61	1.97	1.51	1.00	9.66	6.41	101	1.027	198	80.0	125.4
B.J.	17	73.00	203.21	2.168	13.87	1.90	2.67	4.42	2.18	17.52	8.62	153	1.024	161	67.2	121.1
G.C.	23	68.00	216.16	2.114	8.81	1.41	3.16	2.61	1.21	9.67	4.47	86	1.008	85	22.0	73.5
H.R.	18	66.00	130.23	1.668	8.81	1.59	1.71	-1.24	-0.95	7.45	5.72	84	1.024	160	71.3	112.4
G.W.	17	75.00	199.38	2.193	15.04	2.01	2.55	1.39	0.69	15.88	7.96	137	1.021	150	39.2	103.8

Date - August 12 & 13, 1966   Stored Water   DB = 95F, WB = 89.3F, RH = 80%, ET = 90.8F

Subject	Age (yr)	Ht. (in)	Wt. (lb)	Body Area (m²)	Water In. (lb)	Food In. (lb)	Urine Out. (lb)	Water In. Rate (lb/hr)	Water In. Extrap. 24 hrs	Body Wt. Loss (lb)	Body Wt. Loss Rate (lb/hr)	Sweat Rate (gm/m²hr)	Time to Rise (hr)	Sp.Gr.	Urine Na	K	Cl (milliequ./liter)
G.C.	23	68.00	218.71	2.125	11.45	1.14	3.39	1.21	19.36	1.90	0.20	249	9.50	1.003	36	14.4	16.5
R.R.	18	66.00	132.08	1.678	9.43	1.44	1.64	0.82	13.12	-3.16	-0.27	143	11.50	1.015	70	47.2	64.9
J.H.	24	71.50	177.74	2.021	6.11	1.45	1.18	0.57	9.12	2.32	0.22	183	10.67	1.016	120	49.6	90.8
G.B.	17	67.75	152.00	1.816	11.79	1.69	0.93	0.93	14.88	0.07	0.01	249	12.67	1.025	133	107.2	121.1
J.W.	26	69.50	173.14	1.955	12.33	1.73	3.41	1.19	19.04	-3.30	-0.33	164	10.33	1.023	25	22.4	34.6
B.J.	17	73.00	201.50	2.161	11.92	0.81*	0.47	1.49	23.84	3.76	0.47	420	8.00	1.029	36	136.0	82.2
T.W.	17	72.00	172.59	2.003	7.93	1.26	0.83	0.83	13.28	3.59	0.38	285	9.50	1.028	40	123.2	64.9
G.W.	17	75.00	196.88	2.182	10.86	0.55*	0.46	1.40	22.40	5.01	0.65	440	7.75	1.022	74	72.0	86.5

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		ROLE	WT	ROLE	WT	ROLE	WT
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